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A BORDERS WETLAND VISION:

Development of a Strategic Planning Tool for Wetland Biodiversity Conservation

FINAL REPORT
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Our Scottish Borders
Your environment

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EXECUTIVE SUMMARY

Macaulay Research Consultancy Services Ltd was commissioned by Scottish Borders Council to submit a proposal for the work entitled: A Borders Wetland Vision. The work was originally broken down into five objectives as follows (Figure 2.1):

Objective 1 Modelling of derived and potential wetland areas based on topography, soils, land capability, geology and existing wetland data.

Objective 2 Testing of modelled results against verified wetland inventories.

Objective 3 Subdivision of the outcomes of Objective 1 based on whether the wetland area is already documented in existing datasets or is a potential site.

Objective 4 Assessment of all sites for multi-benefit potential and also for potential constraints.

Objective 5 Identification of a sample of wetland areas prioritised for survey in a later phase.

These objectives were achieved by undertaking rules-based modelling using Geographical Information Systems (GIS). In the GIS, the various datasets were used as filters to identify areas where wetlands currently exist (based on the available data) and where they could potentially exist (based on conditions).

It was determined that, instead of just providing one-off maps, it would be more versatile if the whole modelling system would be delivered, which would allow Scottish Borders Council to re-run calculations to explore "what-if" scenarios as a result of modifications to the delivered models or the incorporation of other datasets.

The resultant change to the Objectives was that a Decision Support Tool (DST), complete with a set of output maps based on agreed rules-based models of habitat constraint, was created. This provided a more flexible approach that would allow Scottish Borders Council to continue scenario testing as required in the light of new data or changing circumstance.

Areas derived from the data by the DST as theoretically existing wetlands are termed 'derived wetlands' in this report and areas extrapolated by the DST as having potential for development as wetlands are termed 'potential wetlands'. Any areas referred to as 'existing' are defined by a dataset that is based on some sort of field study.

A 'Main' dataset was created that included all the attributes that were practical (some attributes such as slope were handled separately due to data-type constraints). The 'Main' dataset includes more attributes than were used in the modelling process to allow simple "reselecting" processes to be carried out on the output datasets to further assist with meeting Objectives 4 and 5. Such attributes identify whether an areas is, for instance, part of an SSSI or near a town.

The Scottish Borders region was classified according to soil-water association (hydrology of soil types - HOST), flood risk, Land Cover Map 2000 (LCM - which was based on satellite remote sensing), class, slope, altitude and underlying rock acidity. Eleven wetland habitat types and three loch types were categorised according to these attributes (Table 3.1). The

categorisations were used to create a rules-based modelling system in ArcGIS 9.1 Model Builder with a separate model for the derived and potential areas of each wetlands type. The rules were based on ecological likelihood of the presence of a wetland type in comparison to the conditions prevalent at any given location. Draft ouputs from the models were presented to the Steering Committee, whose representatives were invited to contribute their local knowledge to fine-tune the models. The outputs have been presented as A0-sized maps (both digitally and as hard copies), ArcGIS Shapefiles[1] and as demonstration versions which can be found in Appendix 2 of this report.

All areas identified as 'derived' wetlands are a refinement on the LCM data and are therefore self-validating within the limits of a desk-based study. All 'potential' wetland areas have the same geophysical characteristics of the derived wetlands but exclude the relevant LCM code (i.e. there is no overlap with the 'derived' areas) and include LCM codes that represent plant communities that have similar requirements to a given wetland type.

The models were found to be good predictors of the presence of wetlands when the derived wetlands were compared to existing wetlands. The total combined area of wetlands derived by the models is shown in map A2.13.

[1] The full models required the ESRI Spatial Analyst extension to ArcGIS 9.1 to run and a simplified version of the DST has been delivered in which the raster datasets have been converted to vectors where possible.

1. Introduction

Scottish Borders Council wished to develop a Wetland Vision for Scottish Borders to guide the future conservation of multi-benefit wetlands at a landscape scale and to facilitate the delivery of the Scottish Biodiversity Strategy, UK Biodiversity Action Plan and Scottish Borders Local Biodiversity Action Plan objectives. Similar studies in Yorkshire and Humberside (Environment Agency, 2005) and by North West England English Nature (2004) helped to inform this decision. This report and the Decision Support Tool on which it is based represent the first outcomes of the Vision. The Background, Purposes and Limiting factors of this study are summarised from the Invitation to Tender (Scottish Borders Council, 2005) as follows:

1.1. Background

Scottish Borders contains some important wetland areas. For the purposes of this study, wetlands include blanket bog, lowland raised bogs, fens, reedbeds, floodplain grazing marsh, the wet component of lowland and upland hay meadows, purple moor-grass and rush pastures, wet woodlands and standing open-water habitats.

Scottish Borders holds nationally important wetland sites such as the Central Borders Specially Identified Wetlands and internationally important lowland raised bog sites but also a broad range of existing and historic wetland sites in need of restoration or enhancement. Over 200 basin mires and fens have been identified. These cover a range of types, from acid nutrient-poor to base-rich fen, throughout the hydroseral succession to open-water margins, and represent the major Scottish resource unrivalled elsewhere in the country. The typical species diversity for these wetlands may be greater, in terms of typical species number and rarity, than, for example, found in Flow Country of Caithness and Sutherland. The sequence and continuous range of mires in close proximity to one another is a feature of considerable importance for genetic transfer between sites and for research and education. Because they are so small individually, and are often in mid-altitude or lowland areas, such wetlands in Scottish Borders have suffered in the past under agricultural and forestry operations and are under threat.

Specially Identified Wetlands within the Central Borders have been subject to maintenance and enhancement under the Environmentally Sensitive Areas scheme and the Rural Stewardship Scheme. Many other wetland areas within Scottish Borders have not been subject to these protective measures and are in need of maintenance and restoration.

Small remnant areas of wet woodland are found in Scottish Borders, and there are also small remaining areas of wet meadow and rush pasture. Some important standing open-water habitats are located within Scottish Borders including mesotrophic lochs at St Mary's Loch and Loch of the Lowes and other sites.

The UK government has published Habitat Action Plans (HAPs) for all major habitats and particularly notable or declining species. The UK Biodiversity Action Plan (UKBAP) is part of the commitment to The 1992 Earth Summit in Rio de Janeiro. Relevant UKBAP priority habitats include reedbeds, coastal and floodplain grazing marsh, fen, lowland raised bog, blanket bog, wet woodland, lowland meadows, upland hay meadows, purple moor-grass and rush pasture, eutrophic lakes, mesotrophic lakes and other standing open-water habitats.

Under Section 1 (1) of the Nature Conservation (Scotland) Act 2004 it is the duty of every public body and office-holder, in exercising any functions, to further the conservation of biodiversity so far as is consistent with the proper exercise of those functions. They must also have regard to the Scottish Biodiversity Strategy and any other strategy designated under the Act as well as the United Nations Environment Programme Convention on Biological Diversity.

Scottish Borders Council coordinates the Scottish Borders Local Biodiversity Action Plan as part of its statutory duty. The LBAP Partnership has Habitat Working Groups to coordinate action for key habitats. The LBAP Wetland Habitat Working Group coordinates actions for wetlands and is convened by the Tweed Forum.

Scottish Borders Council is finalising the Scottish Borders Woodland Strategy, the revised Indicative Forestry Strategy that will provide a strategy for the expansion and enhancement of woodlands within Scottish Borders. The Borders Wetland Vision would complement the woodland strategy by providing a strategic approach to wetland conservation in Scottish Borders.

Wetlands can bring multiple benefits, for example from their intrinsic nature conservation value, addition to landscape quality, buffering against flood events, educational value, community value, tourism value and for certain less sensitive wetland habitats, recreational value and potential uses in diffuse pollution control.

Opportunities for the restoration, maintenance and creation of wetlands may come through the reforms of CAP and implementation of Land Management Contracts and through the implementation of the Water Framework Directive.

An inventory of Scottish Borders wetland sites using existing data and based on local knowledge has been built up for approximately 1,200 existing and former wetland sites, but there is a need to complete and verify this. The project made constructive use of this data set to identify the full range of potential wetland sites in the Borders to guide future catchment level management to ensure hydrological integrity at a landscape scale.

1.2. Purpose and Limiting Factors

The Council and LBAP Partners wished to develop a strategic approach to wetlands so that resources are brought to bear in the areas of greatest need and potential.

The Vision provides a strategic planning tool for biodiversity conservation. It is a broad-scale strategic vision that provides a spatially based Decision Support Tool to help identify where environmental enhancements for wetlands could be delivered in future, using existing wetland areas of environmental value as a starting point. The maps produced under the Vision portray the opportunity space for the delivery of BAP and LBAP targets.

It is proposed that the visioning exercise will also generate a sample of prioritised wetland sites to survey to enable the status and field-condition of these sites to be established. The survey work itself will be a second phase to the project, following on from the creation of this decision support tool. This is an important phase as the outputs of the decision support tool are at a strategic level and are reliant on the quality of the available input data. Scottish

Borders Council hopes that this will, in turn, lead to a third phase to the project, a landscape-scale wetland conservation and restoration programme.

It is envisaged that the outputs of the wetland vision will have a range of potential uses as identified below:

- Assist Scottish Borders LBAP to target actions to meet biodiversity objectives, including the enhancement of habitat networks across Scottish Borders.
- Support Tweed Forum delivery of the Tweed Catchment Management Plan.
- Enable SEPA to target action to meet Water Framework Directive objectives e.g. by using wetlands to control diffuse pollution (as proposed in SEPA’s National Farm Wetlands project).
- Assist SEERAD to target actions under Land Management Contracts and the Rural Stewardship Scheme to benefit wetlands and ensure maximum public benefit.
- Enable Scottish Borders Council and organisations such as Borders Forest Trust and Tweed Forum to target action for community-based projects and local nature reserves. Develop opportunities for access and recreation and community-based biodiversity projects.
- Target wetland restoration and enhancement to help preserve the cultural heritage of Scottish Borders. Wetlands contain some of the best preserved archaeological remains including prehistoric material and palaeoecological information.
- Guide the Council’s Technical Services Department in their development of a sustainable flood management programme in Scottish Borders.
- Provide a strategic planning tool to complement the existing Forest Habitat Network.

2. Methodology

Figure 2.1 is a simple schematic of the original proposed methodology. The basic methodology was to model the theoretical locations for wetlands based on biophysical data and then to compare that to the actual (known) locations of wetlands both to validate the model and to refine it. The difference between the possible location and the known locations is then an indicator of new sites that may have potential for inclusion in a Scottish Borders Wetlands Vision, together with the known sites.

Further analysis of the set of potential wetlands can now allow focus on management factors to determine a subset of all the wetlands that appear to be most promising in terms of the objectives as outlined in the invitation to tender.

The proposed method was based on Geographical Information Systems (GIS) analysis and was designed to be both simple and robust at the strategic level of research. The process of determining the possible areas of wetlands will follow a stepped process of elimination as set out in Figure 2.1.

An important semantic distinction is made in this report. Areas derived from the data by the DST as theoretically existing wetlands are termed ‘derived wetlands’ in this report and areas extrapolated by the DST as having potential for development as wetlands are termed ‘potential wetlands’. Any areas referred to as ‘existing’ are defined by a dataset that is based on some sort of field study.

2.1. Objective 1 - Identification of theoretical wetland areas

2.1.1. Aim

To create a dataset that identifies areas that may be classed as wetlands based on biogeographic factors.

2.1.2. Method

The location of potential wetland areas was determined by developing a series of rules that utilise the following datasets to identify land areas as potential wetlands.

a) Topography – The topography of the study area enabled areas where the slope and altitude are consistent with different wetland types. Height and slope were not incorporated into the 'main' dataset but used as separate layers in the modelling process because these attributes would have had to be converted to averages per polygon and any subsequent intersections of the polygons in the 'Main' data set would then render the averages untrue.

b) Soil data – Soil data, in particular, the Hydrology of Soil Types (HOST – Boorman *et al.*, 1995) was used to identify land areas that have the potential to become wetlands. There are 29 HOST classes, which describe the dominant pathways of water movement through the soil and substrate. Approximately 75% of the SBC area is covered by 1:25,000 soils mapping while the remaining area is covered by 1:250,000 mapping. The detailed mapping was used where it was available, although some areas in the south of the region have poorer resolution data. The HOST classes were used to identify soils that were likely to be wet due to surface water (poor drainage), ground water (poor permeability) or peat. All other soils were considered to be unlikely candidates for wetlands.

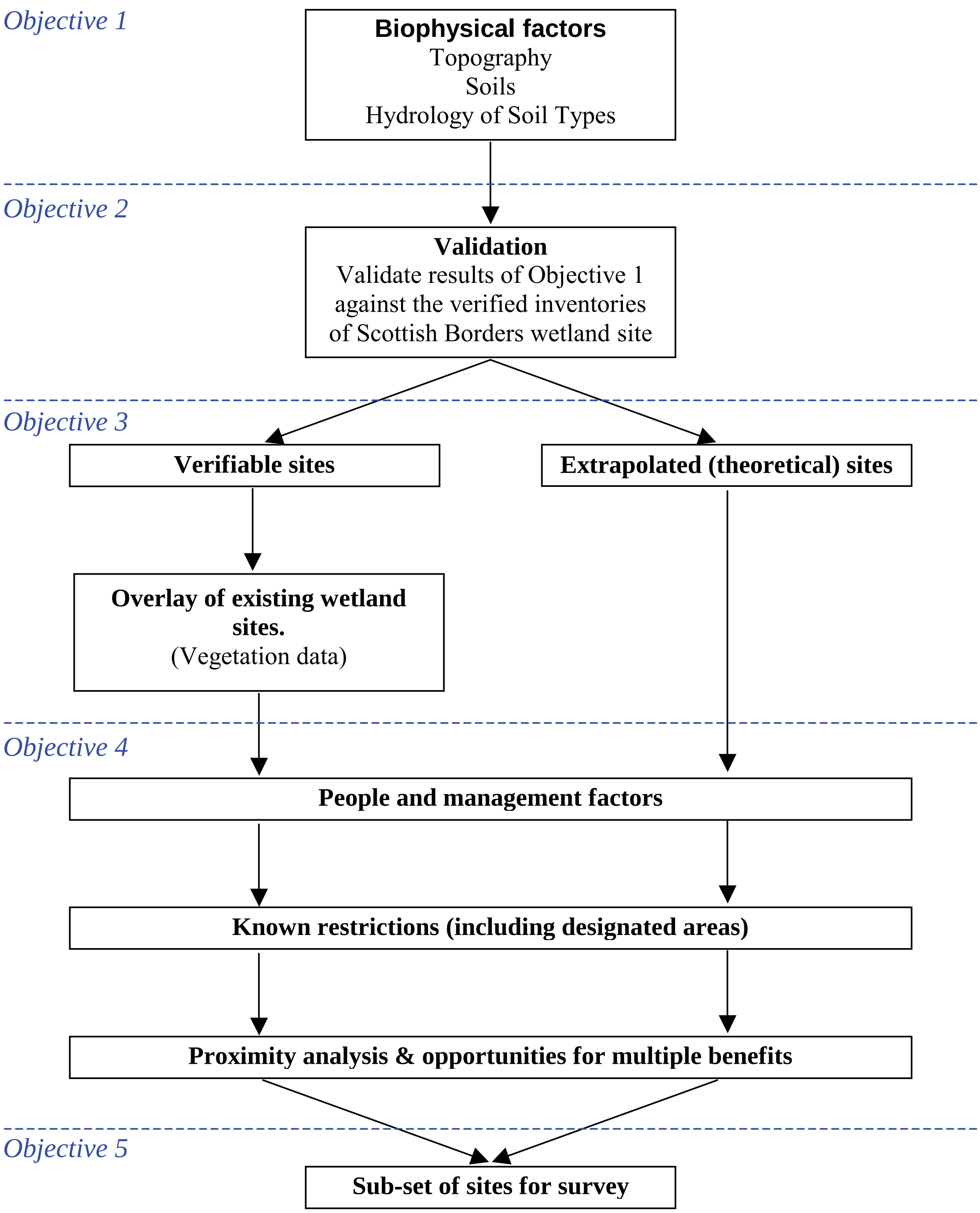
   The physical properties of soils govern the storage and transmission of water within the soil. These properties combine with other soil characteristics to provide chemical buffers and biological filters. HOST classification is based on conceptual models of the processes taking place within the soils and, where appropriate, the substrate. There are 11 response models used in the HOST classification system and these are based on three physical settings:

   1. a soil on a permeable substrate in which there is a deep aquifer or groundwater (i.e. at > 2m depth)
   2. a soil on permeable substrate in which there is a normally shallow water table (i.e. < 2m depth)
   3. a soil (or soil and substrate) which contains an impermeable or semi-permeable layer within 1m of the surface

   These three physical settings give rise to the 11 variations based on different soil properties (e.g. the presence of a peaty top layer) and wetness regimes (as indicated by the presence of gleying). The models describe different combinations of vertical and lateral flow.

c) Lochs and Rivers – Lochs and rivers are indicative of wet conditions (in addition to the standing water that they represent) and polygons in the 'Main' dataset that represent the surrounding low lying areas were identified by an appropriate attribute, allowing for identification of sites with potential based on the extension of the loch margins depending on the soil type and topography.

Figure 2.1: Project Methodology Outline



d) Land Cover – Land Cover Map 2000 (LCM – Fuller *et al*., 2002) data were used to identify areas that have already been classified as a type of wetland. LCM includes categories such as bogs, a fen/marsh, and a swamp category. The Land Cover of Scotland 1988 (LCS88 – MLURI, 1993) dataset which was derived from aerial photography, provided some data for validation purposes and supplementary data for other attributes. However, the classes in LCM and LCS88 are not the same, obviating the combined use of these two datasets. LCM was favoured as the principle attribute for land cover due to its greater concurrency. LCS88 is not better than LCM2000, not least because LCS only identifies areas as 'peat bog' or 'wetland'. LCM at least enables some scope for attempting to identify habitat type. Using LCM and LCS requires an understanding of how the data were derived and it is not appropriate to take a simplistic approach but the limitations of remote sensing must be factored in and this is reflected in the rules base from which the models were derived. Neither dataset is based on field research and so an appropriate range of habitat types needs to be accounted for and simplistic direct relationships between conditions in the field and LCM classes are not appropriate. The rules base allows the LCM codes to be used more as generic habitat identifiers rather than specific habitat types.

e) A dataset describing the underlying rock acidity was also included as a refinement for the geophysical factors.

The process filtered through the datasets, beginning with the topography and successively removed areas that cannot be considered as potential wetland locations.

2.1.3. Outputs

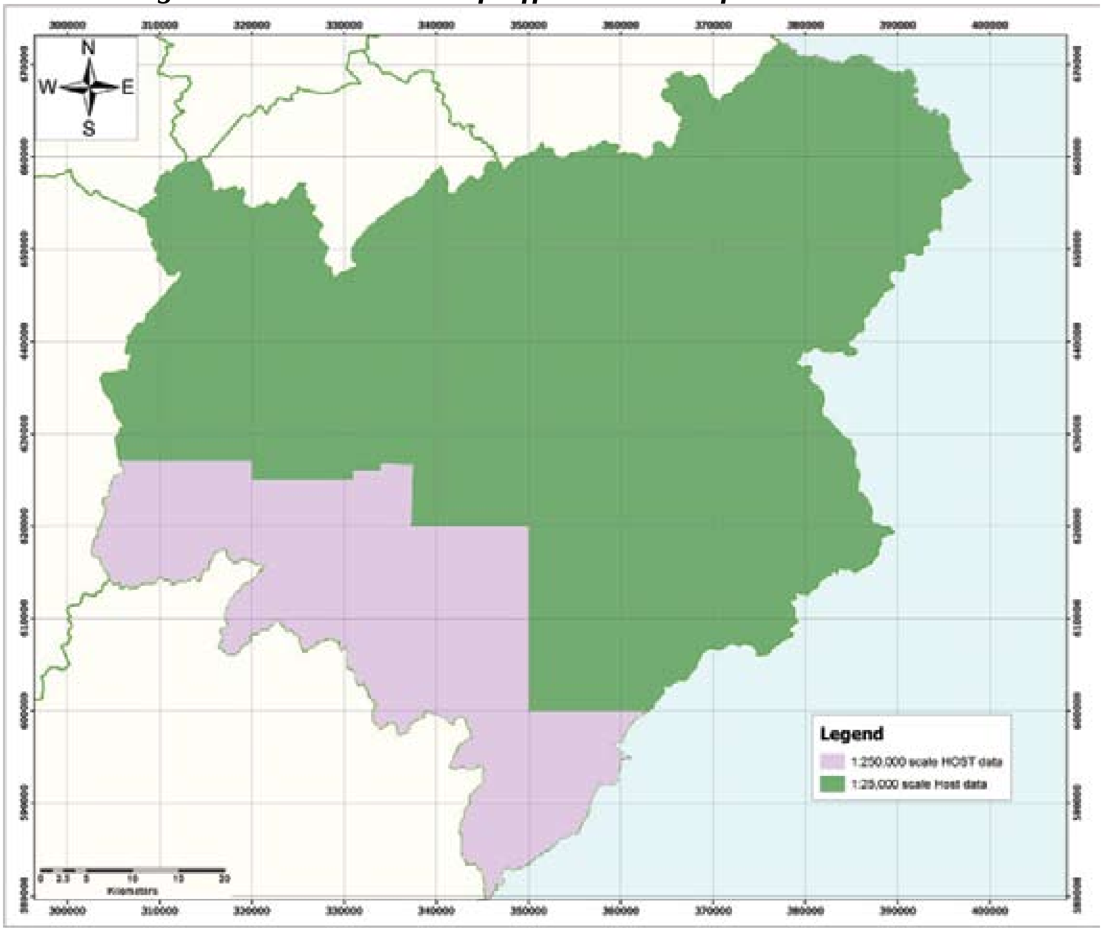
The outputs from this Objective were digital datasets including the first stage of the ‘Main’ dataset plus derived datasets that categorised the altitude and slope of the region.

2.1.4. Key Issues

Although the digital resolution of the data can be mapped at 1:10k as specified in the tender document, few of these datasets were originally at the scale of 1:10k (for instance the soils data in the Scottish Borders area varies across the region at 1:250k and 1:25k, see Figure 2.2 which shows the distribution of the two scales of data) and therefore the resultant dataset cannot be considered as having a scale of 1:10k in terms of the accuracy of the data.

It had originally been intended that some calculation of flow accumulation be incorporated, based on the topographic data. This was used during validation but was not included in the final analysis partly because the interpretation of the results of such a calculation in a meaningful way would go beyond the scope and budget of this project but predominantly because the soil-water association is better defined and more readily interpreted from the HOST classification. The flow accumulation dataset will be provided as a separate output but, while ideal for identifying stream and river networks, the requirement for arbitrarily setting cut-off thresholds to distinguish between bulk stream-flow (through/out of an area) and high surface-flow (into an area) meant that it did not prove as useful as had been hoped.

Figure 2.2: Distribution of different scales of HOST data



2.2. Objective 2 - Validation of the outcomes of Objective 1

2.2.1. Aim

To validate the dataset from Objective 1 and identify the goodness of fit between known wetland areas and modelled wetlands to provide a basis for confidence in the model.

2.2.2. Method

Validation was performed by comparing the Borders Wetland Inventory dataset of known wetland areas with the results of the HOST classification. The approach assumed that the SCB dataset will be a subset of the areas identified in the theoretical dataset (i.e. a direct assessment of the goodness of fit is not appropriate because any wetland areas not documented in the SBC dataset would skew the error).

The comparison was performed in two ways. The first was to look at the coincidence and proximity of the Borders Wetland Inventory point data to the derived outputs and was performed prior to creating the models (see Sections 3 and 4). The second way involved buffering the Borders Wetland Inventory data by 100m and performing a Cohen's Kappa test of agreement using the 'Accuracy Assessor' ArcScript (Mundt, 2006) on the buffered areas and the derived outputs (from the models – see Section 4) that categorised blanket bog, fens, lowland raised bog, purple moor-grass and rush pasture and reedbeds (these being the available categories in the Wetland Inventory

'Priority_H' attribute). Points outside the Scottish Borders area were excluded as were those points where there were no data for the 'Priority_H' attribute (most of which were labelled in other attributes as 'springheads').

Accuracy Assessor is a simple Visual Basic script that is intended to automate accuracy assessments of classifications from remotely sensed imagery in ArcGIS. Accuracy Assessor uses three feature layers to operate, which are a classification layer (a singular, dissolved geometry based on the buffered Borders Wetland Inventory data) as an aerial 'training' dataset and two assessment layers (the undissolved buffered Borders Wetland Inventory data and a combined dataset based on the derived outputs from the models for the wetland types listed in the previous paragraph. It was designed to work with polygon features. Accuracy Assessor will calculate producer's, user's, and overall accuracies for presence and absence of a classified target. The tests of accuracy are calculated in the standard manner, as described by Congalton (1991). The value of Kappa and z-statistic are calculated according to methods described by Foody (2004).

The Kappa test of agreement is the proportion of agreements after chance agreement has been excluded. Its upper limit is k (Kappa) = +1.00 (total agreement). If judges agree at a chance level, k = 0.00. The lower limit of Kappa depends on the distribution of row and column marginals and can fall between 0 and -1.00. A high negative value of Kappa indicates strong disagreement between assessments and is a valid result where the hypothesis is that two areas are NOT the same. Indicative values of Kappa are ±0.50 (acceptable dis/agreement), ±0.75 (good dis/agreement), ±0.90 (strong dis/agreement). For more information on Kappa see Cohen (1960) or Kraemer (1982).

2.2.3. Results

Of the 974 wetland points, 705 (72.4%) lie within areas predicted as having potential for wetlands by HOST (Figure 2.3). Of the wetland habitat types in the LCS88 dataset, 90.3% lies wholly within areas predicted as having potential for wetlands by HOST (Figure 2.4). The intersection of known wetlands (based on the union of wetland polygons from the specially designated wetlands, 'lws-with-wetland component' and LCS88 datasets) and areas predicted by HOST class is 95.67% (Figure 2.5).

The value of Kappa for the test of agreement for the categorisation of polygons (and therefore a real goodness of fit) between the Borders Wetland Inventory and the derived model outputs was 0.97.

Figure 2.3: Coincidence of wetland point data with HOST

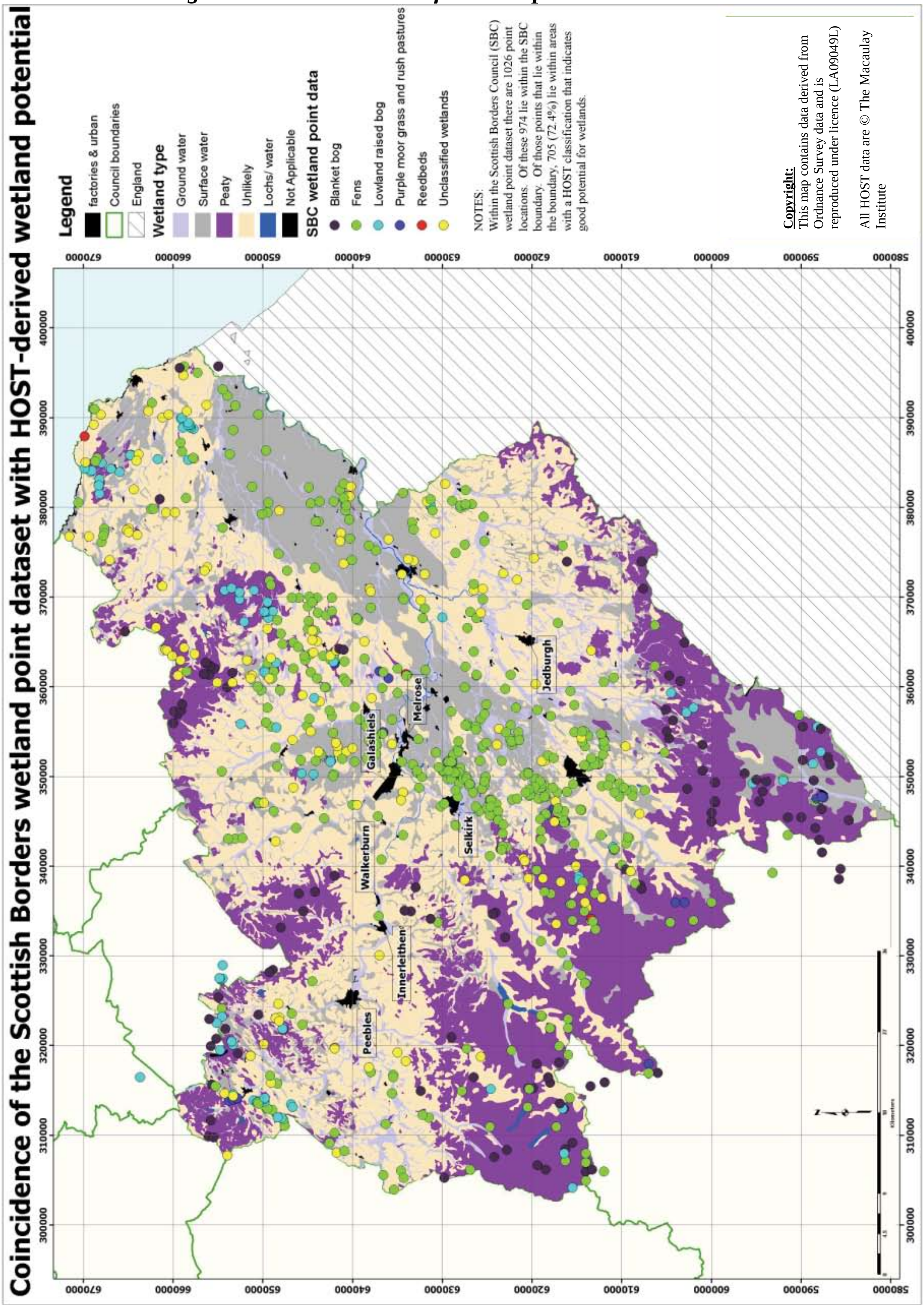


Figure 2.4: Coincidence of LCS88 wetland areas with HOST

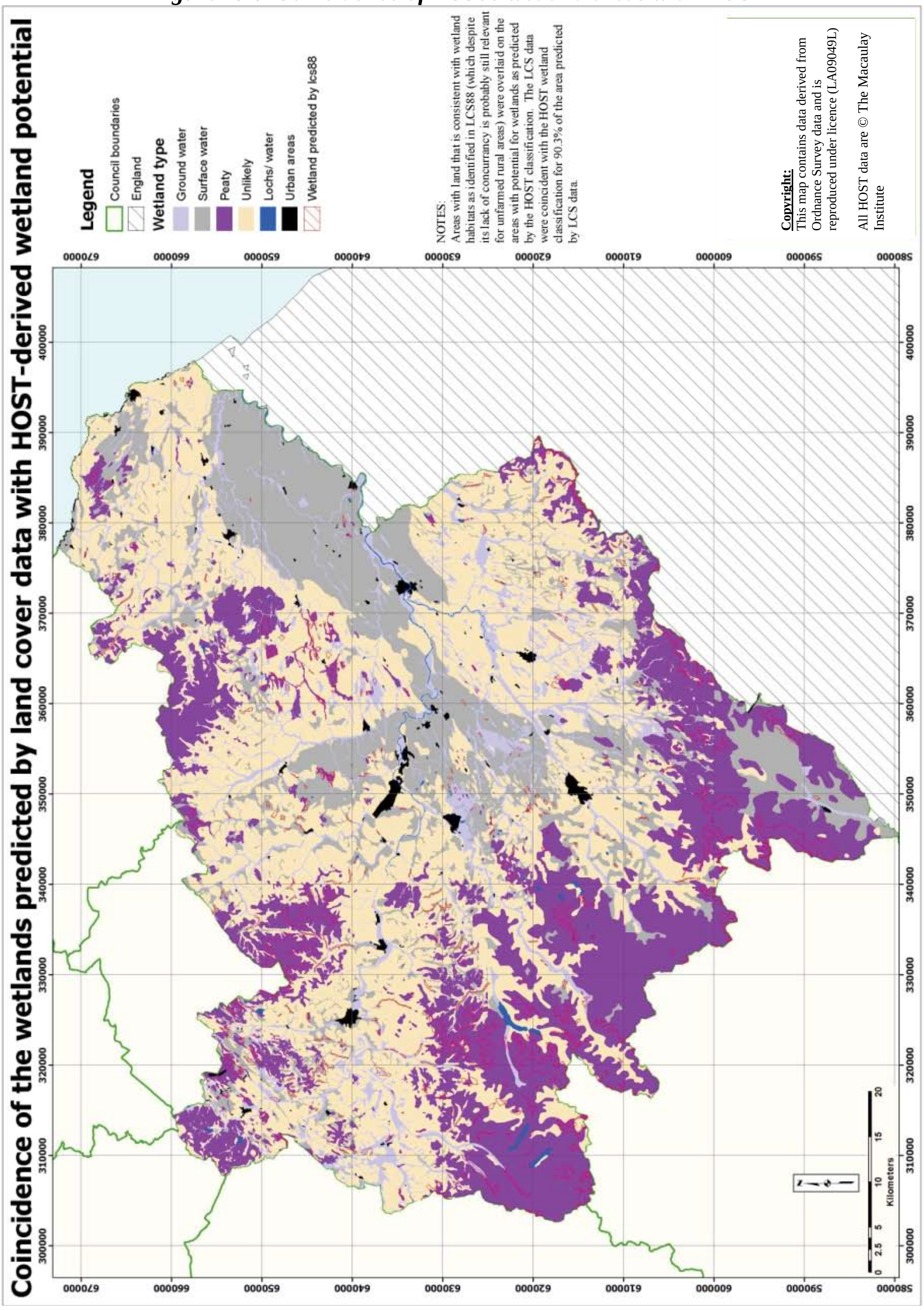
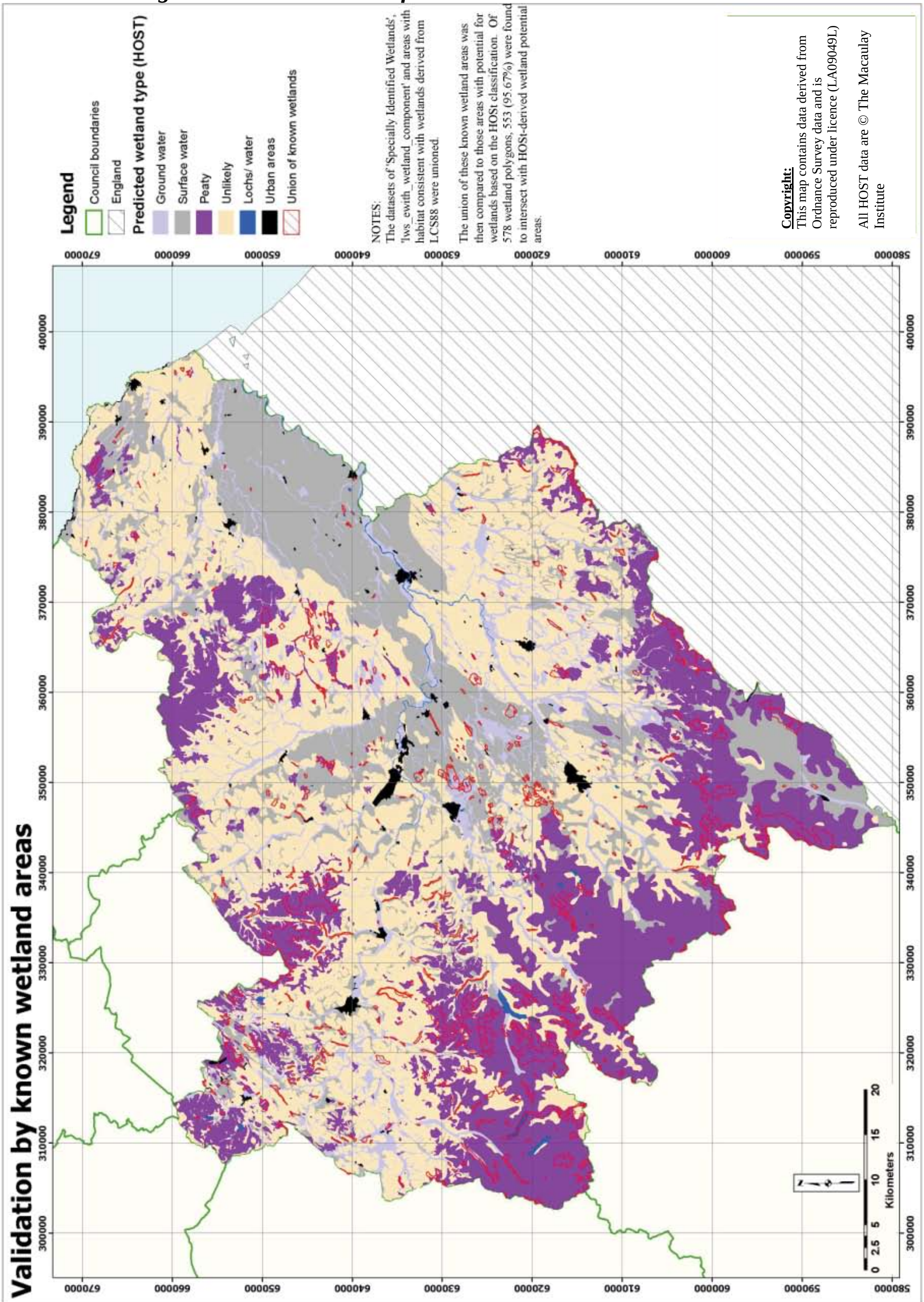


Figure 2.5: Intersection of all known wetland areas with HOST



2.2.4. Key Issues

The validation process has some limitations due to the available data and the limits of the project and true validation can only ever be achieved by field research to ground-truth the outcomes. Some of the datasets used for validation are point data and not ideal. The rules (see Section 4) also rely on LCM classes to derive wetlands and validation with LCM would be a 'self-fulfilling prophecy' that would suggest 100% accuracy. The rules are more restrictive than the LCM classes so the areas predicted as 'derived' wetlands are never more than, and usually less than, the total LCM class area. It would appear that HOST provides a very good predictor of soils with potential for wetland habitats, which, when combined with LCM and other known ecological constraints such as altitude, slope, likelihood of inundation and basal rock acidity, give a robust predictor of both derived and potential wetland sites.

2.3. Objective 3 - Identify wetland areas as 'derived' or 'potential'.

2.3.1. Aim

The original aim was to make a distinction between extrapolated wetland areas and known wetland areas.

2.3.2. Method

As an alternative to the original outcomes, The Macaulay Research Consultancy Services suggested an alternative approach, which was to develop a Decision Support Tool that would allow Scottish Borders Council and the other project partners to re-examine the data to test 'what-if' scenarios. This suggestion had consequences for Objective 3. The original deliverable was being developed along the lines of a single dataset into which attributes identifying whether a wetland was 'derived' or 'potential' would be added. However, with the adoption of a rules-based modelling approach, a more flexible method was developed. The methodology for this will be discussed in more detail in Sections 3 and 4. In brief, it was to create a set of models that could be re-run and in which parameters could be edited to test 'what-if' scenarios. A separate model was created for each wetland type that is capable of generating a new output each time it is run. The set of models for 'derived' wetlands was then duplicated and edited to give a set of models for 'potential' wetlands.

2.3.3. Outputs

The outputs include a full set of models in a pre-prepared ArcGIS project (MXD) document. A full set of outputs from the modelling process is also supplied together with cartographic output. These outputs are described in more detail in Sections 3 and 4 and examples of the maps are shown in the Appendix. The total combined area of wetlands derived by the models is shown in map A2.13. Maps A2.1 to A2.12 show the derived and potential areas predicted by the models as they currently stand.

2.3.4. Key Issues

It was originally anticipated that the data would be delivered as a single raster dataset with a look-up table of attributes. The data are now delivered as individual vector datasets containing multiple attributes that can be further interrogated as a means of satisfying Objectives 4 and 5.

2.4. Objective 4 - Assess sites for multi-benefit potential and potential constraints.

2.4.1. Aim

To assess the potential multiple benefits of wetland areas from Objective 3 and also to identify a sub-set of sites for wetland conservation that do not show conflict with issues such as nitrogen and phosphorous contamination, SSSI, NVZ and other designations.

2.4.2. Method

As no final decision was reached on the specifics of which multi-benefits the project should focus on, the more flexible approach or re-usable models was adopted and will be described in Sections 3 and 4. Briefly, this approach will allow the subsequent analysis of the spatial relationships of the model outputs with any dataset available to Scottish Borders Council, whether it has already been identified by the steering committee or whether it becomes available after the end of the project.

To add greater benefit to this process, additional attributes were added to the 'Main' dataset by performing unions between it and various datasets delineating designated areas. The attributes of the 'Main' dataset are as shown in Table 2.1:

Table 2.1: Attribute classification of the 'Main' dataset

Main Dataset attributes		
Soil wetland potential	derived from HOST (MLURI)	unlikely, slight, good
Wetland type	derived from HOST (MLURI)	ground water, surface water, peaty soil
SSSI	SNH	yes/no
SPA	SNH	yes/no
SAC	SNH	yes/no
RAMSAR	SNH	yes/no
NNR	SNH	yes/no
NVZ	SNH	yes/no
Ancient Woodland Inventory	SNH	yes/no
Borders Grasslands and mires	SNH	yes/no
Intermediate Bog Inventory	SNH	yes/no
Raised Bog Inventory	SNH	yes/no
100 year flood risk	Institute of Hydrology	yes/no
LCM description	CEH	LCM codes (see table 4.1)
Forest habitat network	Forestry Commission Scotland	constraint, existing, arable
Urban zone	derived from LCM and soils datasets	1km 'doughnut' buffer
Loch zone	derived from LCM and soils datasets	100m 'doughnut' buffer
River zone	derived from OS Strategi	100m buffer

The Urban, Loch and River zones allow the outputs of the models to be tested against their proximity to any of these features. The multi benefit in the case of the first two attributes might be recreation or education. The urban areas and lochs were buffered by the distances shown in the table above. The buffers for these two features were created as 'doughnuts'. Urban areas and Lochs have no soils data and so the area inside the ring of the 'doughnut' is not considered. River features are simple linear data and so the 'doughnut' approach was not used and simple buffers were created. The same approach was applied to the dataset of burns but the burns data are supplied separately because the practical limits of polygon subdivision had been reached.

The Borders Wetland Inventory dataset[2] was not included in the 'Main' dataset because it was point data and therefore not susceptible for inclusion. It was not considered appropriate to simply buffer the points for any other purpose than to test for proximity to derived or predicted wetlands because wetlands have not only location and area but also shape, the latter being unpredictable from a point dataset. The Borders Wetland Inventory was therefore reserved as a method of ground truthing the outputs of the models.

2.4.3. Outputs

The attribution of all wetlands, either modelled or actual, with attributes such as proximity to populations, priority woodlands, or other important wetlands or potential for ameliorating pollutants, or protection of archaeological resources. The digital dataset will include a series of attributes that will allow for the investigation of different scenarios given different priorities (i.e. educational opportunity vs. pollution amelioration). A series of maps illustrating the various potential sites and constraints of the various wetlands.

2.4.4. Key Issues

The key issue here is identifying priorities that will then dictate the wetland areas that are most beneficial given certain goals. The outputs of the modelling process can be readily queried to identify particular wetland areas that also coincide with any, or a combination of, the attributes listed in Section 2.4.2 above.

2.5. Objective 5 - Sub-set of sites for survey

2.5.1. Aim

The original aim was to select a sub-set of the sites for field survey in a future phase, such that the sub-set represents a cross-section of the desirable multi-benefits.

2.5.2. Method

It was agreed that the modelling process will be delivered as a rules-based decision support tool to enable Scottish Borders Council to run the appropriate queries after further consideration of the key objectives.

2.5.3. Outputs

An ArcGIS project document, complete with all the models as described in the following Sections of this report, will be delivered.

2.5.4. Key Issues

If any further assistance with scenario-test is required by Scottish Borders Council, Macaulay Research Consultancy Services offers a 'bureau-service' based on the standard charge-out rate current at the time a request is made. A simple email request will be considered sufficient.

[2] A Scottish Borders Wetland Inventory was produced by C. Badenoch (formerly of SNH), Tweed Forum and Scottish Borders Biological Records Centre. Sites are recorded as point references.

3. Development of the models

The models were created using the 'Model Builder' facility in ArcGIS 9.1. They were not translated into scripts so as to allow greater flexibility in response to changing requirements from Objectives 4 and 5 after the hand-over of the project.

'Model Builder' visually represents a GIS workflow (Figure 3.1) and opening any of the functions within a model will allow a user to control the calculation performed by that function. For instance, many of the models in this project make use of 'Select' functions. The SQL query commands are preset to match the attribute classification in Table 4.1. If a variation on the analysis is required at a later date then a user has simply to open the appropriate model, open the relevant 'Select' function and edit the standard select query dialog box.

A separate model has been created for each wetland type. The ArcGIS interface is shown in Figure 3.2. The models have been grouped according to whether it predicts derived or potential wetland areas (Figure 3.3). To run a model, the user needs only to double-click on the appropriate model in the interface.

The output datasets from the models contain all the attributes of the 'Main' dataset and so sub-selections can be performed on these additional attributes to refine an area of search within the original intentions of Objective 5.

The models were originally required the use of the ESRI 'Spatial Analyst' extension to ArcMap 9.1. However, as many of the project partners that formed the Steering Committee did not have access to this extension, a slightly simplified version of the Decision Support Tool was offered by Macaulay Research Consultancy Services as an additional outcome, such that those datasets that lent themselves readily to conversion would be changed to vector data, thus removing the need for Spatial Analysis. Some functionality would be lost because continuous data (e.g. slope) are best represented in a raster format. However, much of the essential functionality would be retained.

Those users who lacked ArcMap and were still using ArcView 3.2 would be able to use the attributes from the 'Main' dataset carried through the modelling process to perform much of their own modelling.

Figure 3.1: Two examples of the modelling process

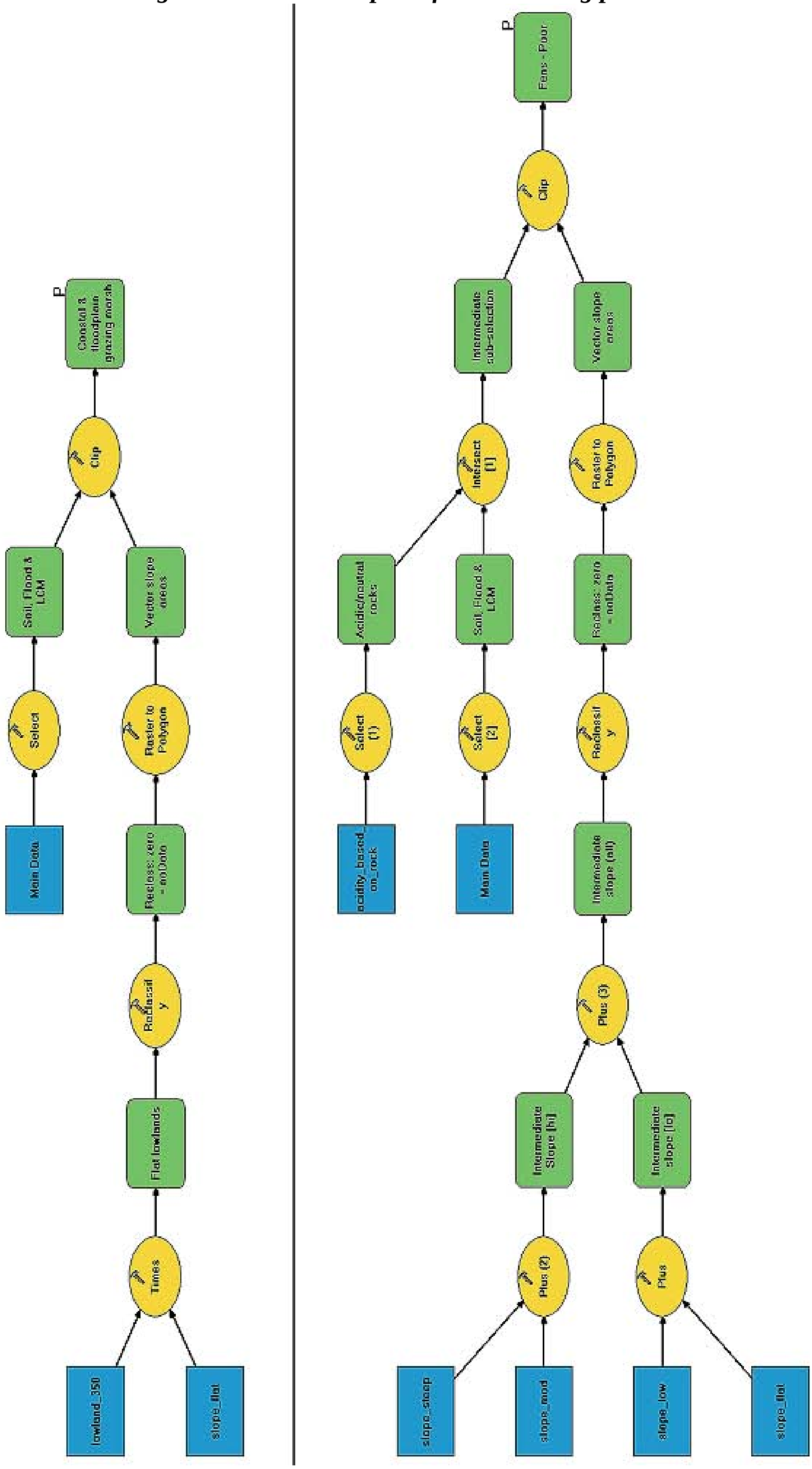


Figure 3.2: The ArcGIS Interface

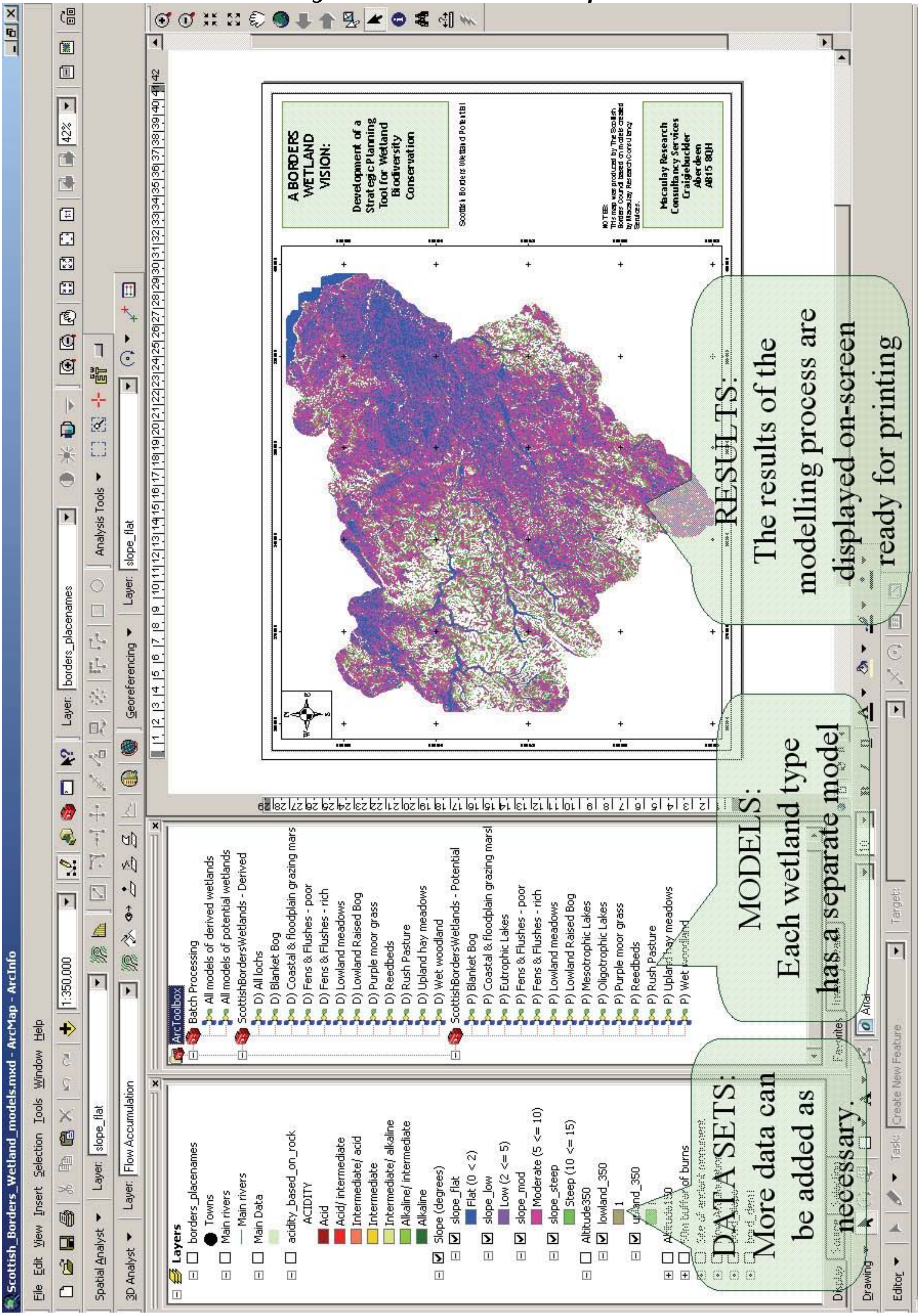
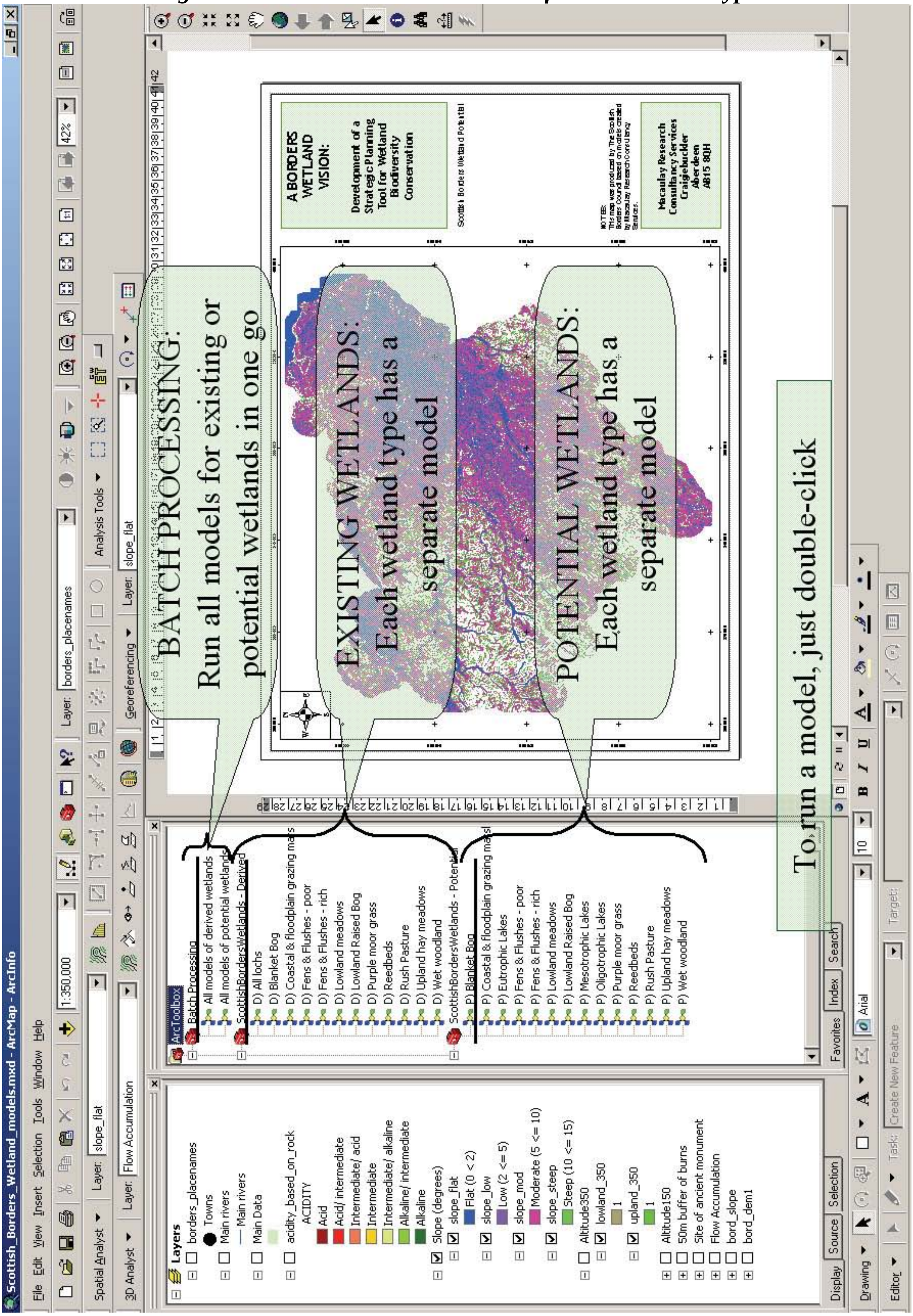


Figure 3.3: There is an editable model for each wetland type



4. ECOLOGICAL ASPECTS OF THE ATTRIBUTES USED TO IDENTIFY POTENTIAL WETLANDS.

4.1. Outline

4.1.1. Table 4.1 shows the different types of wetland vegetation that the Steering Group wanted to identify from the modelling process; these are referred to as *habitats* to help distinguish them from the *vegetation types* recorded in the LCM database. Some of the requested habitats have been sub-divided where we considered that (a) it would lead to more clearly defined results and that (b) the source databases held suitable information to reasonably allow sub-division.

4.1.2. The columns in the table show 'soil water' and other site characteristics that are the principal drivers of the models. The cells of the table show classes of attributes (derived from the databases of those drivers) that were considered suitable for the derived (currently existing) or potential occurrence of each habitat. Collectively, the string of attributes in the table is unique for each habitat - thus limiting the possibility of two or more habitats being ascribed to a single patch of land - and is effectively a 'rules base' for identifying derived and potential areas of each habitat. However, the distribution of similar habitats forms a continuum across some attributes and so a difference in the attribute strings is not necessarily definitive in separating habitats. Therefore the same patch of land may have the potential to become more than one habitat type and so could appear on different habitat maps.

4.1.3. To predict the occurrence of each habitat, areas were mapped using the whole of the attribute string, selecting the 'derived' or 'potential' subsets of the LCM data as appropriate. Like all such models, the results are probablistic rather than definitive and indicate areas where habitats are likely to occur, currently or in the future. The precision of the predictions will differ from one habitat to another - for example potential areas of coastal grazing marshes are extremely limited by their adjacency to coasts and so have a relatively high predictability. In contrast purple moor-grass can develop almost anywhere on moist soils (albeit tending to more acidic types) and its actual occurrence can be mediated by many factors including muirburn and other moorland management practices. It's predictability is therefore fairly low.

4.2. Interpretation Of Attributes

The following points are relevant in the interpretation of the attribute classes:

4.2.1. Soil moisture associations (HOST data): 4 classes -

- 'GROUND WATER' has been generally, but not exclusively, equated with topogenous habitats (i.e. main water movement is vertical).
- 'SURFACE WATER' is associated more with soligenous habitats (i.e. with lateral water movement, often over substrates with poor permeability) or ombrogenous (high rainfall) habitats.

- ‘PEAT’ constitutes a separate category.
- ‘LOCH’ is used in the table as shorthand for any water body although these are predominantly the larger bodies of standing water at the scale of most of the HOST data (1:25,000), and especially in the south-east where the scale is only 1:250,000.

4.2.2. Flood risk

- These data were derived from the Institute of Hydrology’s 100-year flood risk data (IoH, 1996). The data are now hosted by the Centre for Ecology and Hydrology at Wallingford and are an estimate of the areas that would be inundated by floods of the 100-year return period level from non-tidal rivers, in the absence of flood defences. These data have been taken to also represent areas that may be periodically inundated in the short-term.

4.2.3. **LCM** vegetation types (vector data for a minimum mapped area of 400m^2)

- DERIVED distribution of the main wetland vegetation types was determined using level 1 or level 2 of the satellite-derived Land Cover Map 2000 (LCM) data *(see Appendix for definitions)*.
- OTHER POTENTIAL CODES indicate LCM vegetation types that are not currently represented in the database for a particular wetland habitat but have some potential to become that habitat given the right set of conditions. Several types of very wet habitats could develop in areas of shallow water if the water table was lowered by abstraction, drainage or natural processes. Hence the LCM class ‘standing water’ is included in the ‘potential codes’ for some habitats.

4.2.4. **Slope** of the site (pixel scale)

- The four slope classes act as a partial surrogate for flow rates and have been selected to help differentiate some vegetation types e.g. bogs tend to be on flatter areas and have lower flow rates than flushes. Note that the Yorkshire and Humberside study (Environment Agency, 2005) initially used a value of 2.6% as ‘flat’ and later restricted that to 1.06% - no reason is given in the report as to why such exact figures were chosen).

4.2.5. **Altitude** of the site (pixel scale)

- The division between low and high altitude sites was originally set quite low at 150m as it was intended to pick up clear examples of the four habitats mostly delineated by altitude *viz.* lowland raised bogs, reedbeds, coastal and floodplain grazing marshes, and lowland meadows. Representatives on the project Steering Committee were invited to contribute their local knowledge on the applicability of this altitude and it was decided that an altitude of 350m would be more appropriate to the conditions prevalent in Scottish Borders.

4.2.6. **Acidity** of underlying solid geology (1:50,000)

- In the absence of suitable information on soil pH, the acidity of the underlying hard geology has been used as a substitute. All types of rock occurring in the region were ascribed to one of three broad categories - acidic, neutral or calcareous/alkaline.

- In areas overlain by drift, soil pH will not necessarily reflect that of the underlying rock. However, much of the drift in the Borders region appears to have been derived fairly locally and, at least in non-arable areas, the pH of soils should reasonably reflect that of the underlying rock, particularly within the broad classification used.

4.3. Attribute classification used to identify potential wetlands in the Borders Region.

The attributes were then tabulated into a format that could be converted into a rules-based modelling system (Table 4.1). The following notes apply:

1. In most of Scottish Borders, precipitation is not sufficient solely to maintain blanket bog on better-drained areas or steeper slopes. Ditto *Molinia* grasslands.
2. Once bog is established accumulation of peat raises surface above ground water influences and raised bog becomes rainfall-dependent.
3. Fens can be topogenous or soligenous - former (e.g. basin mires) associated with peat formation, either fen peat (mesotrophic mires) or *Spahgnum* peat (acidic mires).
4. Fens were sub-divided to help provide a discriminatory analysis. For the models, 'rich' fens were confined to calcareous types of rock.
5. Several 'derived' fens are SSSIs with 'surface' soil water associations.
6. Fens associated with springs or flushes are found on moderate-steep slopes with high-moderate flows of ground water (separating them from bogs on slopes which are associated more with surface water running through drainage runnels in the peat).
7. Reedbeds are dependent on high water table and so can occur in a wide range of flow rates from riversides to mires, so long as high water table is maintained.
8. Moisture/soil characteristics depend on inundation frequency. Grazings are also management-related (see 9) so are less likely on very unproductive soils. LCM classifies saltmarsh as LS.
9. These vegetation types (and fen meadows) are generally site-specific and a product of agricultural management rather than edaphic characteristics. They are therefore unlikely to be predicted with any worthwhile accuracy from the attributes in this table.
10. Lumping these two types, as asked for in the habitats list, is not very satisfactory. Rush pasture is potentially more ubiquitous than *Molinia* grassland, tolerates a much wider range of conditions (extending to more mineral and less acidic soils, with higher nutrient levels) and can be short-term, depending on management. They have therefore been dealt with separately.
11. Derived (existing) lochs are actual LCM 'standing water' polygons (not modelled – open water bodies are well defined in LCM and match the OS data closely). Potential loch attributes include soils water attribute 'loch' plus a 100m buffer zone.

The Steering Committee were invited to apply their local knowledge to the rules and suggested that the altitude threshold should be changed from 150m to 350m, that upland meadows include areas of flood risk and that the rock acidity category for fens be expanded to cover a wider range within the acid/neutral definition.

Table 4.1: Attribute classification as a pre-cursor for the rules-based modelling

Habitat	Soil water assocn.	Flood risk	LCM CLASS (*see code list, right*)		Mean slope	Altitude	Rock acidity
	Ground, **S**urface, **P**eat, **L**och	including periodic inundation (Y/N)	Current	Other potential codes for future habitat	**F**lat $<2^{O}$ **L**ow $2<=5^{O}$ **M**oderate $5<=10^{O}$ **S**teep $>10^{O}$	**L**ow <=350m **H**igh >350m	**A**cidic **N**eutral **C**alc (alk)
Blanket bog	P	N	BO	SO AG SW	FLM[1]	LH	A
Lowland raised bog	P[2]	N	BO	SO AG SW	FL	L	A
Fens/flushes - rich [3,4,5]	GS	YN	O	CG IG SW	FLMS[6]	LH	C
Fens/flushes - poor [3,4,5]	GSP	YN	O	AG NG IG SW	FLMS[6]	LH	AN
Reedbeds[7]	G	YN	O	AR CG IG LS NG SW	FL	L	NC
Coastal & floodplain grazing marsh[8]	GSP	Y	IG LS	AG CG NG	F	L	ANC
Wet woodland	GS	YN	BW CW	AG BO CG SD IG NG SO	FLM	LH	ANC
Lowland meadows[9]	GS	YN	AG CG IG NG	AR	FLM	L	ANC
Upland hay meadows[9]	GS	YN	AG CG IG NG	AR	FLM	H	ANC
Purple moor-grass[10]	GSP	N	AG	BO BW CW SD SO	FLM[1]	LH	A
Rush pasture[10]	GSP	YN	AG CG IG NG	AR	FLM	LH	ANC
Eutrophic lochs *(potential)*[11]	*Loch zone*	N	SW	AR AG CG IG NG	F	LH	ANC
Mesotrophic lochs *(potential)* [11]	*Loch zone*	N	SW	AG CG IG NG	F	LH	ANC
Oligotrophic lochs *(potential)* [11]	*Loch zone*	N	SW	AG BO NG	F	LH	A

Code in table	Relevant LCM 2000 classes
AG	Acid grassland
AR	Arable and horticulture
BO	Bog
BW	Broadleaf woodland
CG	Calcareous grassland
CW	Coniferous woodland
IG	Improved grassland
LS	Littoral sediment
NG	Neutral grassland (pH 4.5 - 5.5)
SD	Dwarf shrub heath - dense
SO	Open dwarf shrub heath
SW	Standing water
0	No data

5. HABITAT ATTRIBUTES AND MODEL OUTPUTS

5.1. Blanket bog

5.1.1. Attributes:

The rules-base attribute list aims to identify areas of blanket bog within the LCM 'bogs' category, which does not differentiate between types of bogs. Steep slopes (i.e. more than 10^{o}) have been excluded from the models because annual precipitation is less than 1500mm in most of the Borders region and this is probably insufficient to maintain blanket bog on better-drained areas or steeper slopes. Conversely, the inclusion of standing water in 'other potential codes' covers the unlikely eventuality of land being exposed due to the lowering of the water table of shallow water bodies, perhaps due to drainage. LCM vegetation types with the potential to be blanket bog are acid grasslands (most probably *Molinia*-dominated on these peat soils) and open-canopy dwarf shrub heaths. Indeed, some areas classified by LCM as open dwarf shrub heath, may actually be blanket bogs with at least 25% cover of dwarf shrubs.

5.1.2. Outputs

Derived areas of blanket bogs are identified by the model as mainly confined to the principal hill plateaux where rainfall is high, with only a few relatively small sites at lower altitudes, presumably on basin peats.

Potential areas are frequently contiguous with the derived high altitude areas, suggesting a reasonable level of predictability for this habitat, but there are also large areas of 'potential' blanket bog indicated at lower altitudes. As noted above, some of these may in fact be existing blanket bogs that have at least 25% cover of dwarf shrubs (either due to them being slightly drier sites or due to low grazing levels) and so were not classified by LCM as 'bog'. As rainfall decreases with altitude and towards the east of the region, conditions become marginal for ombrogenous blanket bog and potential areas become scarcer, although such habitats may develop in peaty hollows or where drainage is poor.

(See map A2.1)

5.2. Lowland raised bog

5.2.1. Attributes:

Here the attributes are similar to blanket bogs but are confined to land below 350m altitude and exclude any slope greater than 5^{o}, although even this slope may be too great because raised bogs generally require negligible drainage to develop. Raised bogs can take hundreds of years with minimal interference to develop and so the identification of potential areas is almost hypothetical in practical conservation terms.

5.2.2. Outputs

Derived - areas identified by the model as likely to be lowland raised bog were relatively few and included major features such as the area centred on the Haresford Burn, partly coincident with the Gordon Moss, and the Dogden and Hule Mosses.

Potential - the models identify two major concentrations of potential areas of lowland raised bog, though there is a large number of other sites, some barely visible on the output map. The first large area is in the north-east of the region and is partly contiguous with derived bogs in this area as it encompasses parts of the Dogden, Hule and Polwarth mosses between Dye Water and Blackadder Water, the north-eastern catchment of Eddleston Water, and a large area of broken ground between Leadburn and the Gladhouse reservoir.

The other major concentration is south-west of Selkirk, essentially comprising the upper catchment of Ale Water. Most of these potential sites are very close to the 350m upper limit for 'lowlands' requested by the steering group.

The adjacency of potential areas with some of the derived areas that are known to be mosses/bogs suggests a reasonable level of predictability for this habitat type.

(See map A2.2)

5.3. Fens/flushes

5.3.1. Attributes:

The LCM category is titled 'fens/marsh/swamp' but does actually include flushes - for convenience we have abbreviated it to 'fens/flushes'. To cover the possibility of there being large areas of flushed hillsides, moderate and steep slopes were included in the attribute lists.

The reflectance characteristics of fens/flushes are not well defined and are inadequate for reliable detection either by satellite imagery, such as LCM, or other remote sensed imagery such as aerial photography. Also, the extent of these habitats is generally small and the combination of these two factors means that most areas in Scotland are below the discrimination level of LCM - in fact none were identified by LCM in the Borders region. Consequently the identification of derived areas of this habitat are determined principally by the other attributes in the models.

The vegetation types used in the determination of potential areas of fens/flushes was based on LCM grassland because they were most likely to have similar spectral qualities to fens and flushes. Arable land was excluded because the combination of ploughing, fertilisers and pesticides was unlikely to permit the development of fens/flushes of any worthwhile conservation value. Also, had arable been included, there was likely to be a considerable coincidence with potential areas of lowland meadows and one of the aims of the models was to minimise such multiple designations. The LCM 'standing water' category, which includes rivers and streams, was included in the criteria for potential areas as the fringe vegetation to these areas could be targets for investigation.

The fen habitat was sub-divided into 'rich' (calcareous) and 'poor' (acidic/neutral) classes based on the acidity of the underlying rocks. It was presumed that rich fens overlie substrates that would be too alkaline for peat to form in depth, hence the exclusion of the 'peat' soil water association attribute. Similarly the attribute list confined the LCM acid and neutral grassland categories to the 'poor' fens.

The occurrence of fens is generally very site-specific and localised and can only be reliably determined by field studies. Hence the predictability of these habitats by the models is low, although locations of potential 'rich fens' are more predictable because of the limited occurrence of suitable geology.

5.3.2. Outputs

Derived poor fens/flushes - the model identified only a few small areas of this habitat. The majority were identified as coastal features, forming an almost continuous area within the Pease Bay Coast SSSI, with a few sites near St. Abb's Head. Four other locations were identified north-east of Langholm and these appear to be associated mainly with flushed hillsides.

Potential poor fens/flushes - the output map shows a very large area of potential fen/flush which emphasises the point that the actual occurrence of these habitat is decided by local conditions and so the criteria for their occurrence cannot be determined accurately from remote sensing or at the scale of the current models. The actual distribution of potential poor fens is more likely to be small dispersed areas associated with LCM grasslands, often near watercourses, but the flushes could occur almost anywhere where there is an impenetrable substrate, whether of soil or solid rock.

Derived rich fens/flushes - none were indicated by the model.

Potential rich fens/flushes - two major areas were indicated to the north-west and south-east of Kelso, both areas being apparently associated with burns and drains running south-west to north-east at right angles to the eastern syncline of the underlying rock. A third large group of potential fens/flushes was identified around Auchencorth Moss, south-east of Penicuik, with a string of areas associated with the burns running parallel to the A701 from Leadburn to Biggar, most of which in the north, drain into Lyne Water or, in the south, into Holms Water.

(For poor fens see map A2.3. For rich fens see map A2.4)

5.4. Reedbeds

5.4.1. Attributes:

As with fens/flushes, these are below the discrimination levels of LCM when they occur in areas of less than approximately 0.25ha. The attributes list reflects the fact that reedbeds can develop almost anywhere where the water table is consistently high (c. 30cm above ground level in summer) but are mainly confined to more mesotrophic lowland areas. Standing water was included to cover the eventuality of reeds establishing in shallow lochs, although most existing lochs would be too deep for this to occur except at the periphery. Littoral sediments were included to cover the possibility of reedbeds in coastal slacks.

5.4.2. Outputs

Derived reedbeds – virtually no areas were identified by the model.

Potential reedbeds - the model clearly picks out the association between reedbeds and fairly level land adjacent to both standing and running water, particularly along the broad valley of the Tweed. However, very local conditions and water tables would be important (and beyond the scope of the current models) - consequently the area indicated is almost certainly an over-estimate.

(See map A2.5)

5.5. Coastal and floodplain grazing marsh

5.5.1. Attributes:

The location of these habitats is determined principally by physiography and proximity to waterbodies, both running and standing. Grazing marsh is included in the LCM 'improved grassland' category whereas grazed saltmarsh is included in 'littoral rock and sediment'.

While there can be some floodplain marshes at higher altitudes, it was considered that they were likely to be most extensive and prevalent in flat areas in the 'low' altitude class i.e. below 350m. Both habitat names refer to '*grazing* marshes' and so only areas that are currently classified as grasslands were considered likely to have the potential to fulfil that criterion of usage.

5.5.2. Outputs

Coastal grazing marshes - no derived or potential areas were identified by the models, predictably so considering the rocky coastline of the region.

Derived floodplain grazing marshes - areas identified in LCM were all classed as improved grasslands. All the likely areas were represented by small and mostly discontinuous patches alongside the rivers and their major tributaries. There was a relatively large grouping on the Tweed at Innerleithen and others close to the junction of the Tweed and Teviot near Kelso. The most continuous stretches of this habitat were along the Teviot downstream of Hawick and, particularly, the Liddel Water and its tributaries in the south of the region.

Potential floodplain grazing marshes - relatively few potential areas were predicted by the model and most of them were contiguous with derived areas, thus suggesting potential for expansion of the habitat away from the watercourses (e.g. on the Tweed west of Galashiels) or for habitat linkage along the watercourses (e.g. on the Teviot north of Jedburgh).

(See map A2.6)

5.6. Wet woodland

5.6.1. Attributes:

Some sort of woodland is likely to be the natural climax vegetation type on most types of wetland and its absence is usually due to grazing or other management practices. Hence almost any vegetation type has the potential to develop into some type of woodland and therefore very few attributes have been excluded for determining potential areas. However, it is important to note that *peat* has been excluded from the attributes because there are other habitats of higher conservation priority (e.g. bogs and poor fens) that are limited to peat soils. One effect of this exclusion is that many areas of existing woodland (often commercial) that are planted on peaty soils do not appear on the woodlands map.

5.6.2. Outputs

Derived wet woodlands - the derived areas are relatively small and in fairly isolated patches compared with the potential areas of wet woodlands. As mentioned previously, the larger continuous areas in the south of the region are probably artefacts of a change in the scale of the underlying data.

Potential wet woodlands - the distribution of potential wet woodlands is so wide that it is difficult to use the maps for targeting purposes but clearly illustrate that there is great scope for linking the fragmented existing (derived) woodlands.

(See map A2.7)

5.7. Lowland meadows

5.7.1. Attributes:

'Meadows' is a broad descriptor and includes a wide range of grasslands that are traditionally defined by their principal use of being mown for fodder (usually coupled with some aftermath or autumn/winter grazing) as opposed to more or less continuous grazing (i.e. pasture). Although the term 'meadows' is often used to imply damp grasslands, this usage is not consistent, hence meadows are determined more by management than by any edaphic or hydrological characteristics. Their predictability on the basis of attributes in the rules-base is therefore relatively low. .

LCM includes hay meadows in 'improved grasslands' but all of the LCM grassland types have been included in the attributes for 'derived' meadows because of the low ability of satellite sensors to discriminate levels of grassland management. Similarly, the LCM satellite sensors detect vegetation boundaries rather than structural ones and so some unenclosed, unmanaged grasslands may be shown on the outputs if they have a similar spectral signature to adjacent enclosed meadows. Arable land is the only additional vegetation type that might reasonably develop, or be developed, into lowland meadows of reasonable productivity (see 'other potential codes').

5.7.2. Outputs

Derived lowland meadows - these show a fairly predictable distribution that is widespread but fragmented and of low frequency in the more arable areas and becoming more common with increasing altitude up to the 350m altitudinal limit of 'lowland'. However, it must be emphasised that these higher altitude areas may also include some rough hill grazings.

Potential lowland meadows - most vegetation types can become grassland, given the right management, and the potential areas are predominantly derived from the more arable areas that infill between derived grasslands in the productive lowlands.

(See map A2.8)

5.8. Upland hay meadows

5.8.1. Attributes:

The requirement for these to be *hay* meadows makes identification impossible, not only from satellites but even on the ground, because use can vary from year to year. Consequently they have had to be redefined as *wet or damp upland grasslands.* This habitat is separated from the lowland meadows only by the altitude criterion.

5.8.2. Outputs

Derived upland 'hay meadows' - the areas shown are effectively the wetter grasslands above 350m. These may or may not be managed and therefore include grassy hill grazings. Actual hay meadows are likely to be a small proportion of the relatively scarce area shown in the map.

Potential upland 'hay meadows' - the area of these is negligible.

(See map A2.9)

5.9. Purple moor-grass (*Molinia)*

5.9.1. Attributes:

Molinia is included in the LCM 'acid grassland' vegetation type but, as mentioned previously, can develop almost anywhere where the soil is moist, although usually tending to soils that are acidic, often peaty and not high in nutrients. The area for potential *Molinia*-dominated grasslands is therefore very large and its distribution is often determined by local management. For example damp or wet open-canopy heaths are particularly susceptible to invasion by *Molinia* if they are over-grazed or burnt too frequently. Similarly, *Molinia* is often dominant beneath wet upland woodlands and loss of the canopy cover, either through old age or clearance, can allow it to grow and expand very rapidly. Clearly the models cannot take such spasmodic variables into account but the susceptible vegetation types are included in the model.

5.9.2. Outputs

Derived purple moor-grass - there is considerable overlap between this map and that for blanket bog, particularly on the hill slopes. This is not surprising as the interface between these two habitats is very wide with *Molinia* tending to occur at the drier end of the range. The two habitats are not differentiated within the LCM classification so presumably have very similar spectral characteristics.

Potential purple moor-grass - *Molinia* can grow on many of the damp upland soils and this is clearly shown by the 'potential area' map. Whether it does so will depend considerably on local management and grazing levels, as mentioned previously.

(See map A2.10)

5.10. Rush pasture

5.10.1. Attributes:

Whereas *Juncus articulatus* and *J. acutiflorus* grow on almost saturated soils, *J. effusus* can grow on almost any soils that are moist (albeit tending to the more acid soils) and so rush pasture dominated by the latter species can develop in a wide range of sites. In this case, the distribution of rush pasture is often determined as much by management (particularly grazing intensity) as it is by soils, topography or climate. Rushes are suppressed by heavy grazing, particularly in springtime, and consequently have low cover but this increases very rapidly when grazing is reduced. Above ground cover can therefore be very transient. However, rushes have a long-term soil seed bank of up to 10^6 seeds per m^2 so can re-establish very quickly when conditions allow. The occurrence of rush pasture is therefore unpredictable.

5.10.2. Outputs

Derived rush pasture - the ability of rush pasture to develop in almost any grassland is clearly indicated by the map, which basically shows the likely distribution of all types of grassland in the region.

Potential rush pasture - the only additional attribute for potential rush pasture is the inclusion of arable land (although this would require two changes to occur i.e. to grassland followed by the invasion of rushes). The 'potential area' therefore represents the arable land in the region, infilling between the grasslands in much the same way as was seen for lowland meadows.

(See map A2.11)

5.11. Lochs (all)

5.11.1. Attributes:

Derived lochs were not modelled but are polygons taken directly from LCM, which consistently detects lochs larger than 0.5ha and more than 50m wide. These, and potential areas of lochs, were sub-divided according to the acidity of the underlying rock to provide some guidance on the likely acidity/nutrient levels of derived and potential sites (note the inclusion of 'arable' for potential eutrophic lochs only).

Potential sites for lochs are mainly determined by topography and preliminary runs of the models identified few areas other than extensions to the derived (existing) waterbodies. Consequently, it was considered that a more accurate assessment would be achieved by replacing the soil water association attribute of 'loch' with 'loch zone', obtained by placing a 100m buffer zone around the original attribute sites. Due to topography being the major influence, any vegetation type likely to be in the area was included in the 'potential LCM attributes' list.

Flood risk areas are, by definition, subject to sporadic accumulations of water but for most of the time are fairly well-drained, often because they are relatively flat. Consequently flood risk areas were excluded from the attributes for potential loch sites because:

- most were included anyway in the100m buffer zone;
- where these areas are more extensive and occur alongside moving watercourses, they were unlikely to be suitable for the development of lochs of any depth unless major constructional work is undertaken to impede drainage by the watercourse and to substantially raise water levels;
- similarly, to expand lochs into any flood risk areas that surround them but lie outside the buffer zone would usually require substantial interference with the drainage from the loch which would have knock-on effects for other habitats.

5.11.2. Outputs

Derived lochs

The map shows all the LCM water bodies (i.e. mostly larger than 0.5ha and mostly wider than 50m wide) without any sub-division according to acidity (although that information is still available within the models).

Potential lochs

For output purposes, the potential eutrophic and mesotrophic lochs have been combined and only the areas of potential oligotrophic lochs shown separately. The models mainly show expansions of derived lochs into surrounding vegetation but there are many other small potential sites, the vast majority of which appear to be less than 1ha and predicted to be eutrophic or mesotrophic. Many of these small sites are away from the main watercourses but there are some notable concentrations, especially along the broader parts of the Tweed valley above and below Kelso.

The outputs suggest a reasonable level of probability for the potential sites indicated, although the success of establishing lochs in these locations can depend on topographical differences of only a metre or two, which is beyond the discrimination of the current models.

(See map A2.12)

6. Conclusion

The Decision Support Tool approach to producing strategic-level habitat identification and restoration maps appears to work well. The models allow ‘what-if’ scenario testing as well as the later addition of other data for a closer integration of the outputs into the decision making process. As the models are used, it is expected that an ever-increasing depth of local knowledge will be fed back into the models to update the rules on which they are based, thus constantly refining them to improve their accuracy. The method is transportable to other locations but the rules used in the models would have to be edited for any given area, depending on the unique combination of environmental factors at play in that location.

The next stage of the Borders Wetland Vision process is to utilise the derived outputs and the Decision Support Tool to investigate the opportunities and constraints for multi-benefit wetland management further.

7. References

Boorman, D.B.; Hollis, J.M. and Lilly, A (1995) *Hydrology of Soil Types: a hydrologically-based classification of soils of the United Kingdom*, Institute of Hydrology, Report No. 126.

Centre for Ecology and Hydrology (2000) *Widespread Broad Habitats and LCM2000 Classes*, accessed from: *www.ceh.ac.uk/sections/seo/documents/leaflet3.pdf*

Cohen, J. (1960) *A coefficient of agreement for nominal scales*. Educational and Psychological Measurement, 20, 37-46.

Congalton, R.G. (1991) *A review of assessing the accuracy of classifications of remotely sensed data*. Remote Sensing of Environment, 3735-46.

English Nature (2004) *Developing a Strategic Approach to Wetland Conservation in the Lowlands of Northwest England: A Pilot Study in Three Natural Areas*, English Nature, Peterborough.

Environment Agency (2005) *The Yorkshire and Humber Wetland Restoration Feasibility Study*, Final Report.

Foody, G.M. (2004) *Thematic map comparison: Evaluating the statistical significance of differences in classification accuracy*. Photogrammetric Engineering & Remote Sensing, 70(5), 627-633.

Fuller, R.M.; Smith, G.M.; Sanderson, J.M.; Hill, R.A.; Thomson, A.G.; Cox, R.; Brown, N.J.; Clarke, R.T.; Rothery, P.; and Gerard, F.F. (2002) *Countryside Survey 2000, Module 7, Land Cover Map 2000, Final Report*, Centre for Ecology and Hydrology.

Institute of Hydrology (1996) Flood risk map for England and Wales, accessed from: *http://www.ceh.ac.uk/products/publications/documents/IH130FLOODRISKMAP.PDF* , Report No. 130 (IoH is now part of the Centre for Ecology and Hydrology).

Kraemer, H.C. (1982) Kappa coefficient. In S. Kotz and N. L. Johnson (Eds.), Encyclopedia of Statistical Sciences. New York: John Wiley & Sons.

MLURI, (1993) *The Land Cover of Scotland: Final Report*, A report for the Scottish Office Environment Department, Aberdeen: Macaulay Land Use Research Institute.

Mundt, J. (2006) *Accuracy Assessor*, Public domain visual basic script available from: http://arcscripts.esri.com/details.asp?dbid=14426

Scottish Borders Council (2005) *A Borders Wetland Vision, Consultant's Brief,* Invitation to tender.

APPENDICES

A1. LCM Classes

The following tables can be accessed from:

www.ceh.ac.uk/sections/seo/documents/leaflet3.pdf

The full LCM report can be obtained at:

www.cs2000.org.uk/Final_reports/M07_final_report.htm

Broad Habitats (BHs) and their distinction in LCM2000.	
1. Broad-leaved, mixed and yew woodland	Broad-leaved woodland in stands > 5 m high with tree-cover > 20%; or scrub < 5 m with cover > 30%. Mixed woodland is included if broadleaved trees in conifers cover > 20%. Stands ≥ 0.5 ha are mapped as separate blocks.
2. Coniferous woodland	Coniferous woodland, semi-natural and plantations, with cover > 20%, and recently felled forestry. Once felled areas are colonised by rough grass, heath or scrub they take that class.
3. Boundaries and linear features	Larger linear features such as shelter belts or motorways; smaller linear features (hedges, walls, smaller roads) are only recorded by the field survey.
4. Arable and horticulture	Annual crops, recent leys, freshly ploughed land, rotational setaside, and perennial crops such as berries and orchards. Once setaside is substantially vegetated with weeds or rough grass, it is included in the Improved grassland Habitat.
5. Improved grassland	Improved grasslands in swards dominated by agriculturally 'preferred' species, generally 'improved' by reseeding and/or fertiliser treatment. May be used for agriculture or amenity. Fertile pastures with *Juncus effusus* are included. Setaside grass is included but, where possible, distinguished at the subclass level; abandoned or little-managed Improved grasslands may be confused with semi-natural swards.
6. Neutral grassland 7. Calcareous grassland 8. Acid grassland	Acid, neutral and calcareous semi-natural swards are generally not reseeded or fertiliser-treated; they are dominated by lower productivity grasses, perhaps with many herbs. Grassland management may obscure distinctions from Improved grassland. Neutral, calcareous and acid components are distinguished at subclass level using a soil 'acid sensitivity' map. Pastures with *Juncus effusus* and with semi-natural spectral-characteristics are included with acid swards.
9. Bracken	The bracken Habitat is, at the height of the growing season, dominated by *Pteridium aquilinum*. Where images pre-date the late growing season, or where stands are dissected, bracken may be missed.
10. Dwarf shrub heath	Ericaceous species and gorse forming > 25% of plant cover; open and dense heaths are divided at subclass level. The Habitat includes wet and dry categories but ericaceous vegetation on peat ≥ 0.5 m deep is recorded as 'bog'. In contrast, LCMGB 1990 used a definition based on presence of seasonal standing water.
11. Fen, marsh and swamp	Vegetation which is permanently, seasonally or periodically waterlogged. Swamps, fens and flushes are seldom extensive enough to map from satellite images. Rush pastures are more extensive. The category does not include fertile pastures with *Juncus effusus*.
12. Bog	Bogs include ericaceous, herbaceous and mossy vegetation in areas with peat >0.5 m deep; ericaceous bogs are distinguished at subclass level. Inclusion of Ericaceous bogs contrasts with LCMGB 1990 where bogs were herbaceous or mossy in seasonal standing water.
13. Standing open water and canals 14. Rivers and streams	Water bodies ≥ 0.5 ha are mapped, but only the wider canals and rivers (>50 m) are shown. LCM2000 does not distinguish standing from flowing water.
15. Montane Habitats	Prostrate dwarf heath, sedge and rush, moss heaths and snow bed communities. Limited access during field reconnaissance may limit the accuracy of distinctions.
16. Inland rock	Natural and man-made bare ground, including waste tips and quarries.
17. Built-up areas and gardens	Urban land, rural development, roads, railways, waste and derelict ground, including vegetated wasteland, gardens and urban trees. In LCM200, all larger areas of vegetation (≥ 0.5 ha) are identified as the appropriate cover class. Continuous urban and discontinuous suburban cover are distinguished at subclass level.
18. Supra-littoral rock 19. Supra-littoral sediment	Supra-littoral Habitats, created by coastal processes of erosion and/or accretion, lie above mean high water spring tides; distinction used a maritime mask. Separation of rock and sediment was at subclass level, through spectral and interactive processing.
20. Littoral rock 21. Littoral sediment	Littoral Habitats lie below mean high water spring tides in a zone defined by a maritime mask. Rocks and sediments were separated at subclass level by semi-interactive processing. Littoral rocks are generally limited in extent; sediments may be extensive. Saltmarsh is included with Littoral sediments, but as a separate subclass.
22. Inshore sublittoral sediment	Areas of sea and estuary are assumed to be inshore and with sublittoral sediment. Thus 23. Inshore sublittoral rock, 24. Offshore shelf sediment, 25. Offshore shelf rock, 26. Continental shelf slope and 27. Oceanic seas are not distinguished in LCM2000.

For further descriptions see: **Jackson, D.L.** 2000. JNCC Report No. 307. *Guidance on the Interpretation of the Biodiversity Broad Habitat Classification (terrestrial and freshwater types): definitions and the relationships with other habitat classifications.* Joint Nature Conservation Committee, Peterborough.

A2. Example output maps

All the results of the modelling process have been delivered to Scottish Borders Council as both high-resolution picture-file format (JPEG) maps and digital data (ESRI Shapefiles). The maps on the following pages are for illustrative purposes.

Figure A2.1: Blanket Bog

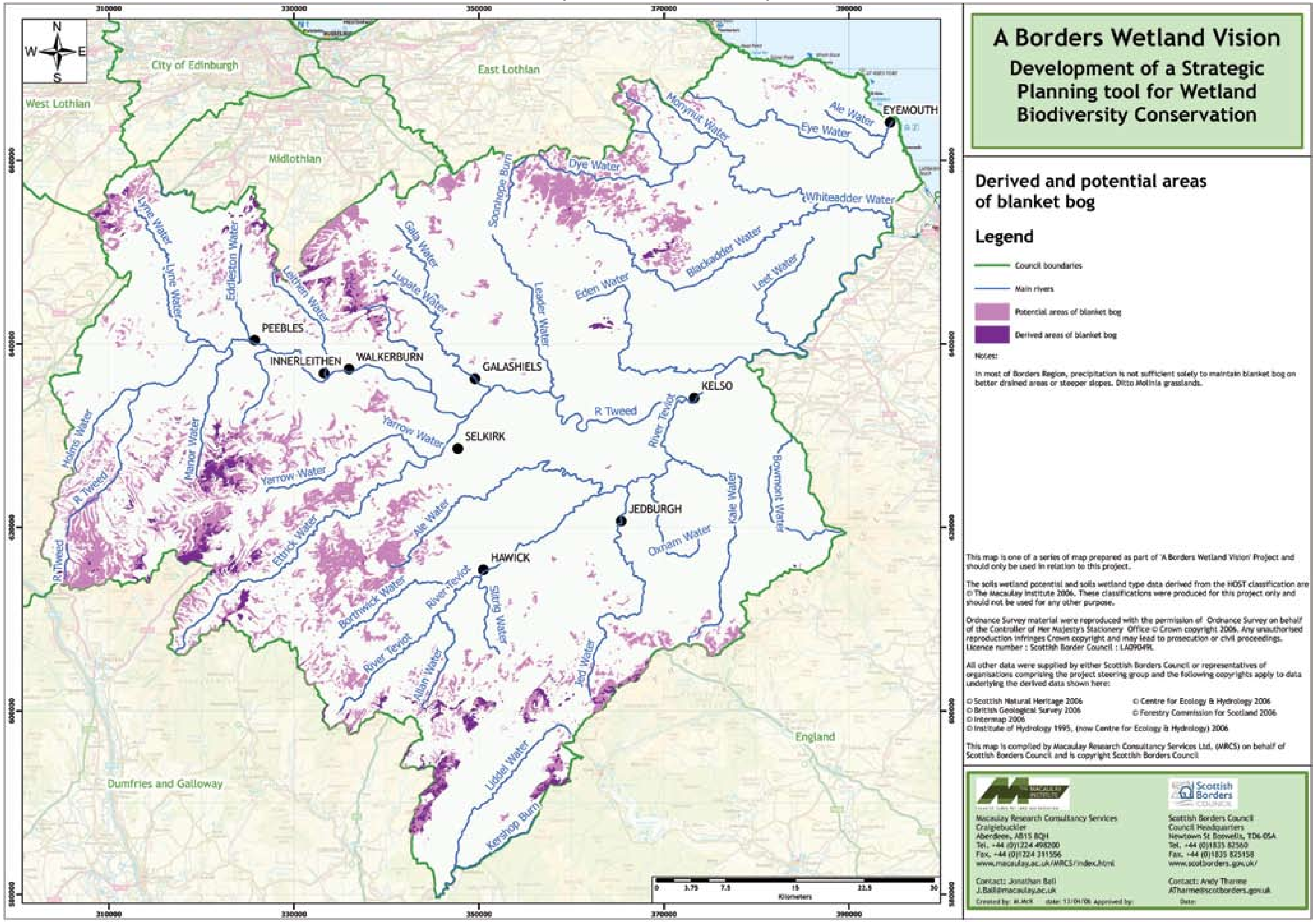


Figure A2.2: Lowland Raised Bogs

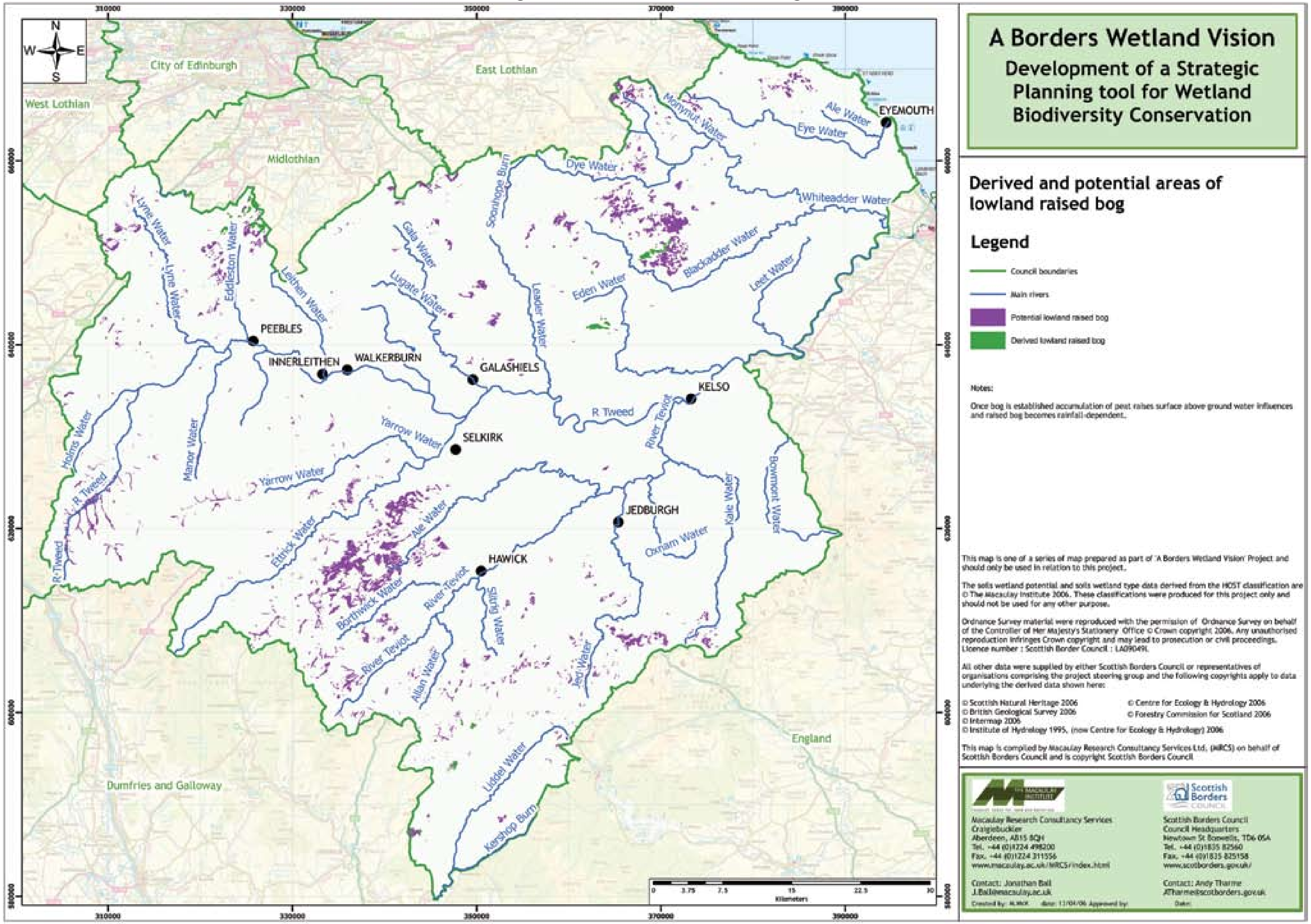


Figure A2.3: Fens-poor

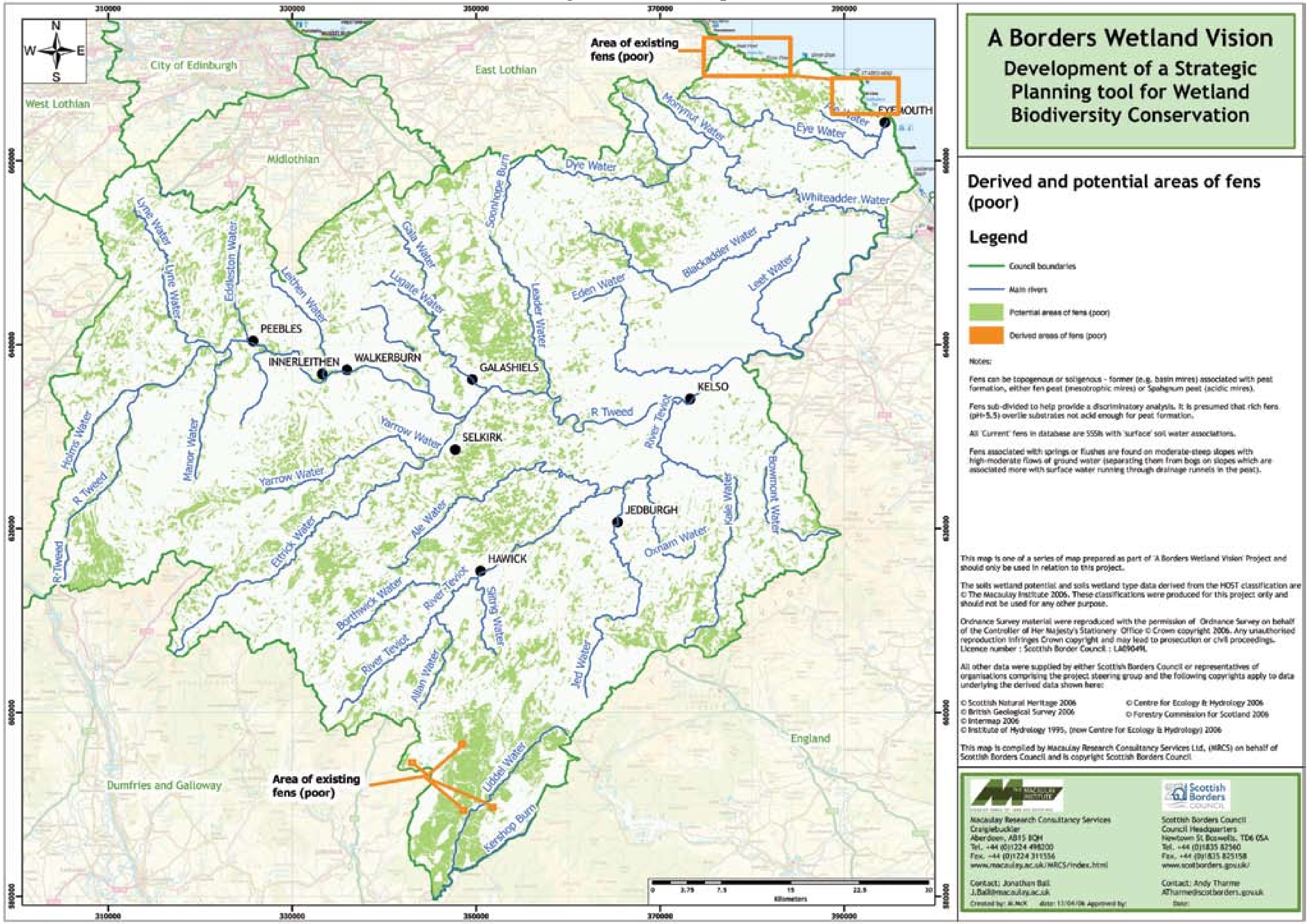


Figure A2.4: Fens-rich

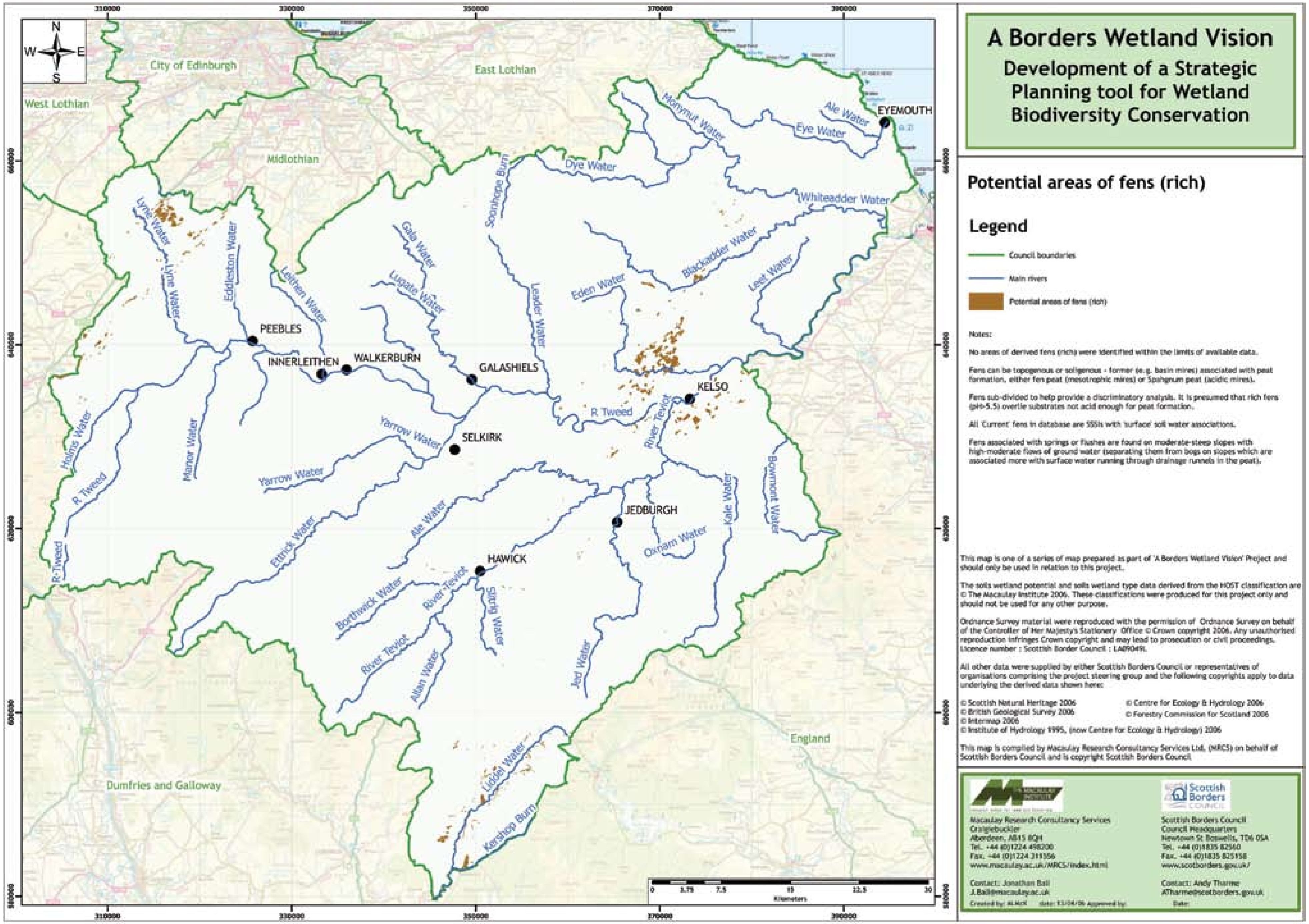


Figure A2.5: Reedbeds

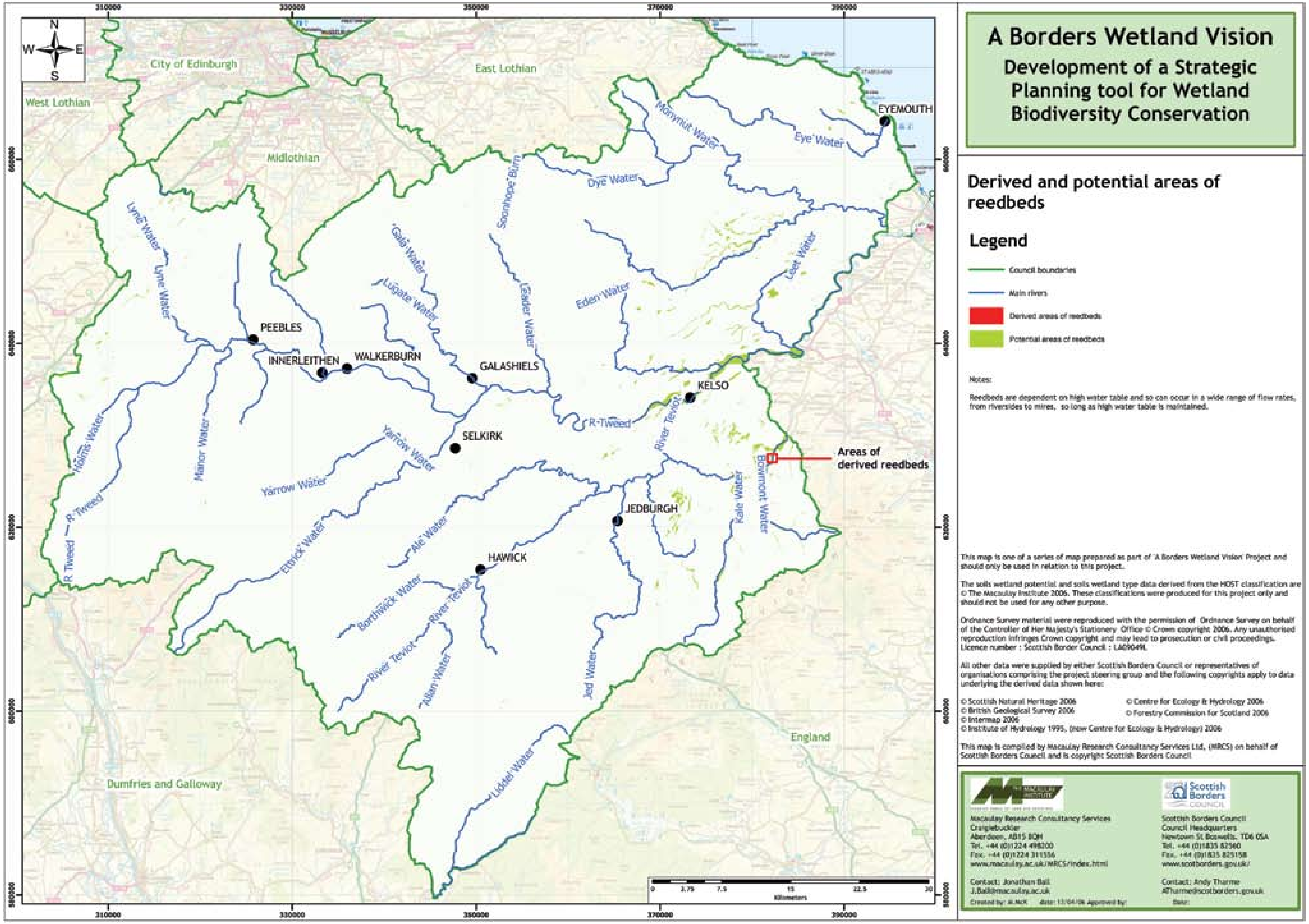


Figure A2.6: Coastal & floodplain grazing marsh

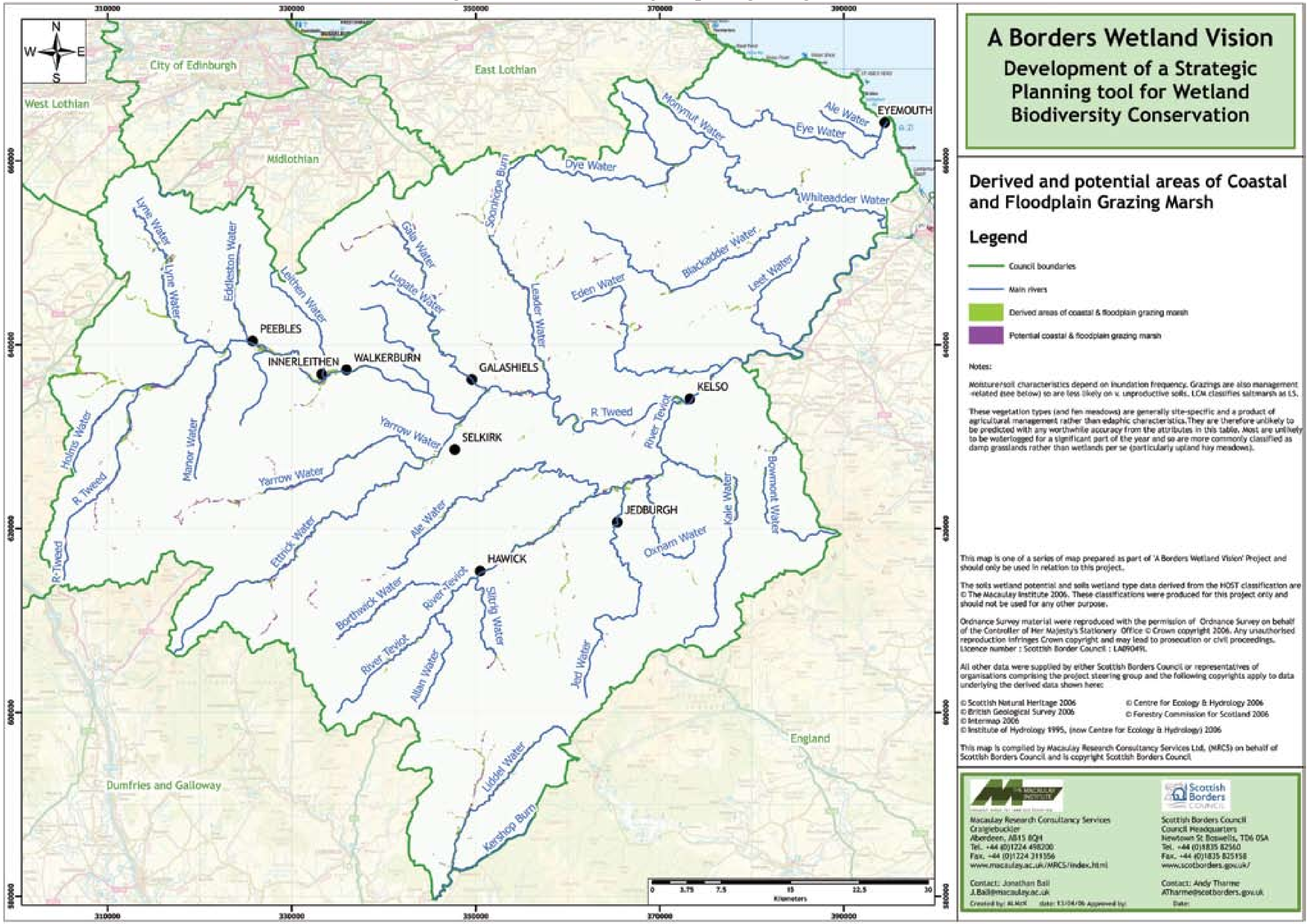


Figure A2.7: Wet woodlands

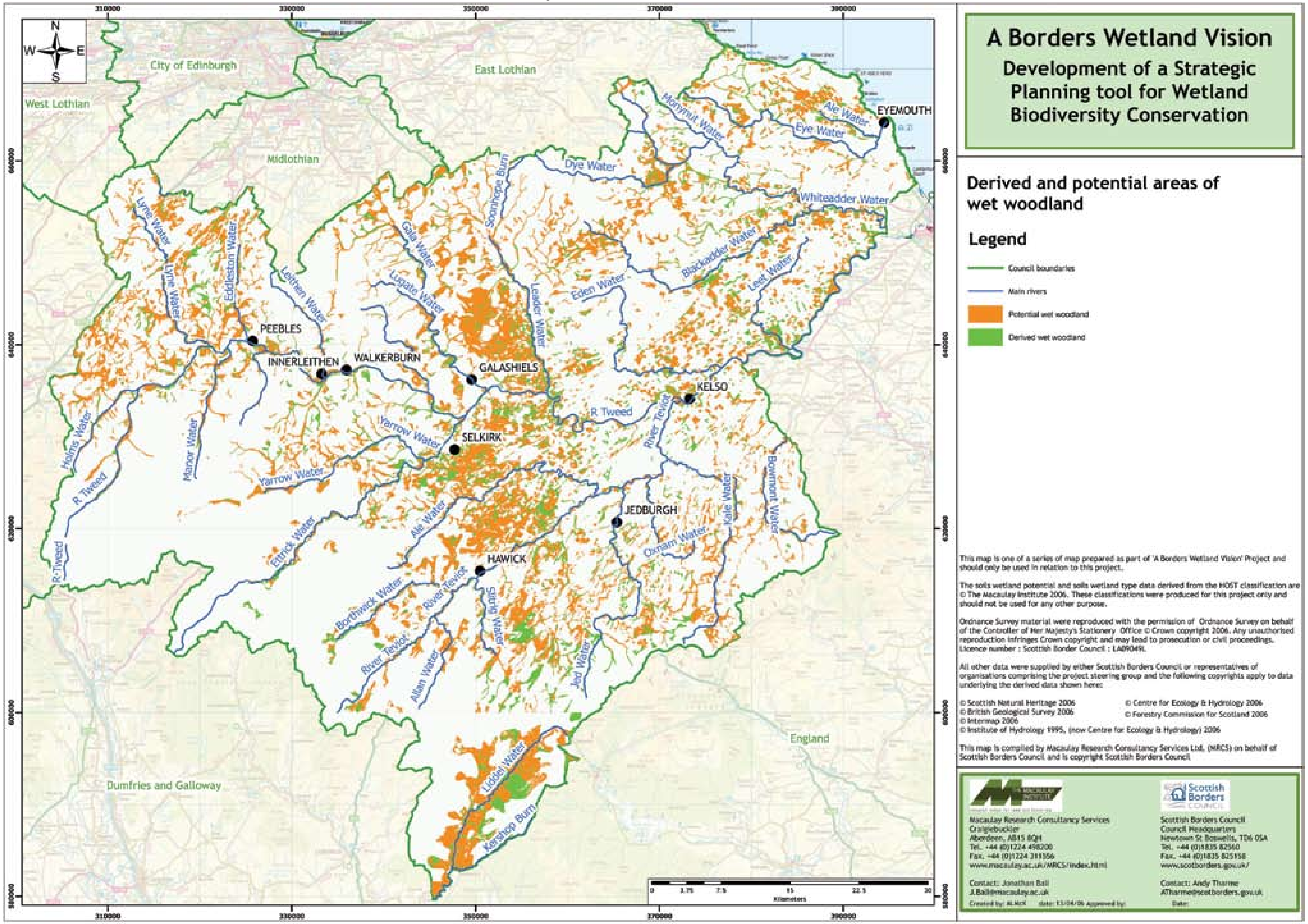


Figure A2.8: Lowland meadow

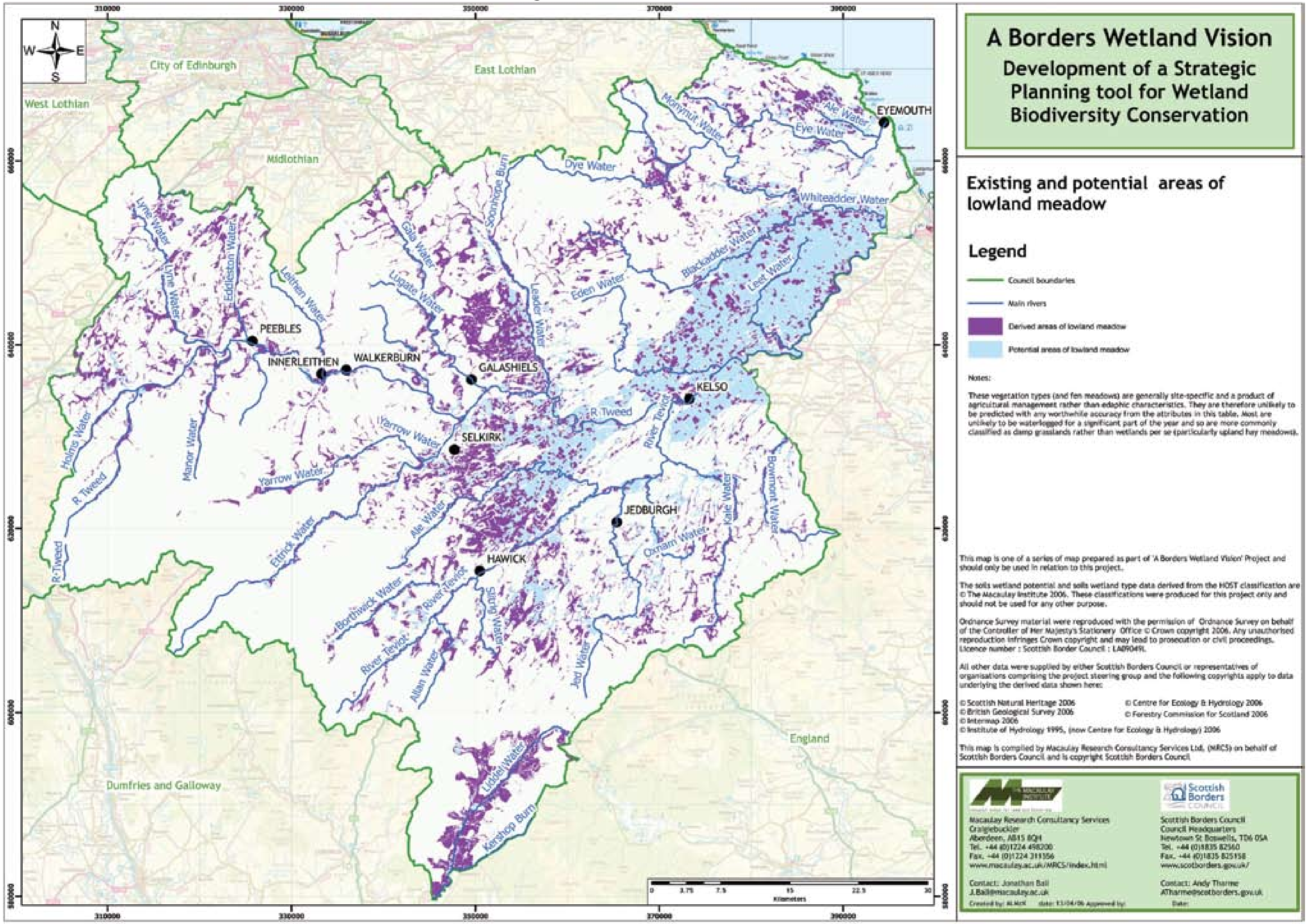
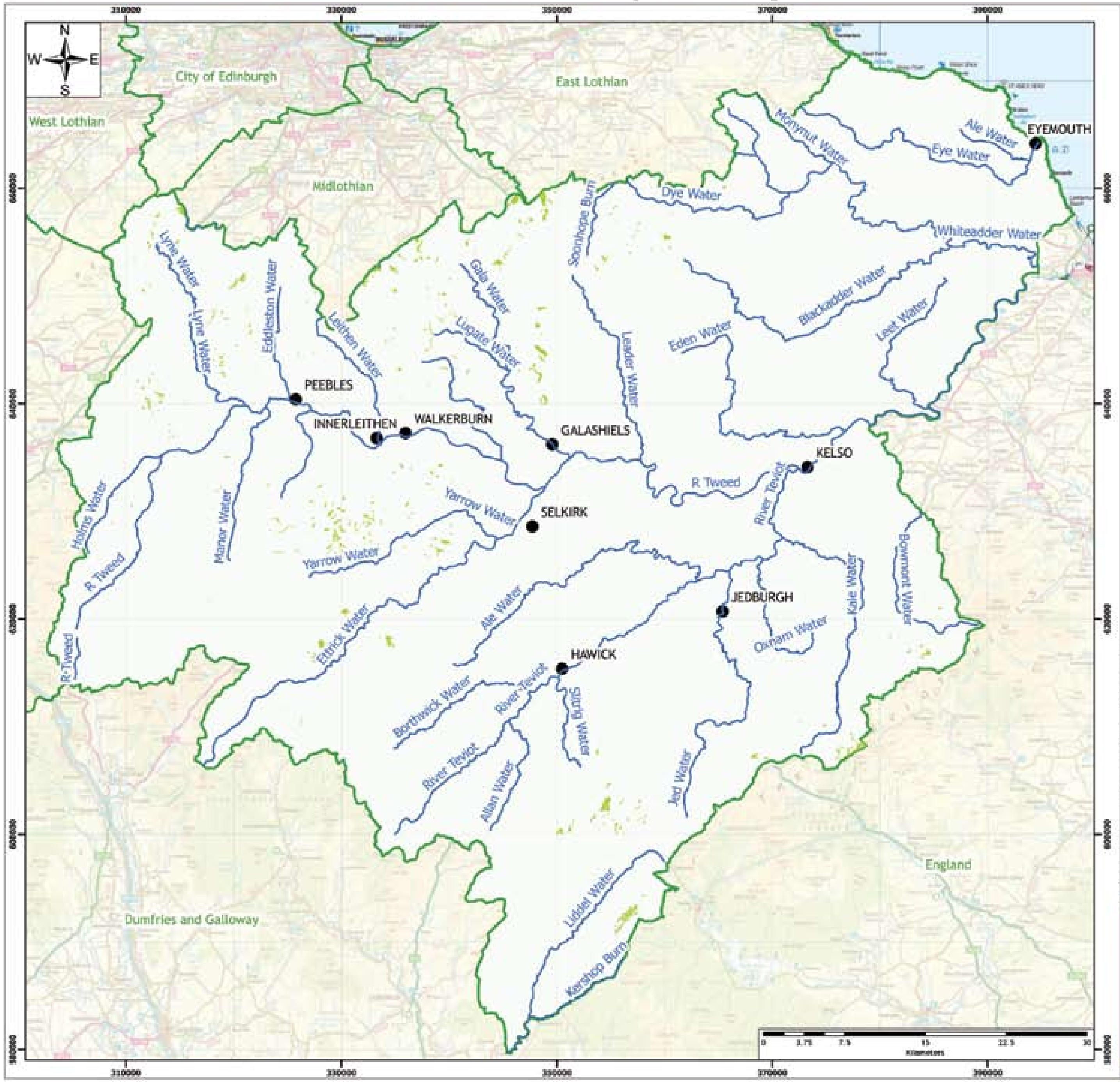


Figure A2.9: Upland meadow



A Borders Wetland Vision

Development of a Strategic Planning tool for Wetland Biodiversity Conservation

Derived and potential areas of upland hay meadow

Legend

- Council boundaries
- Main rivers
- Potential areas of upland hay meadow
- Derived areas of upland hay meadow

Notes:

These vegetation types (and fen meadows) are generally site-specific and a product of agricultural management rather than edaphic characteristics. They are therefore unlikely to be predicted with any worthwhile accuracy from the attributes in this table. Most are unlikely to be waterlogged for a significant part of the year and so are more commonly classified as damp grasslands rather than wetlands per se (particularly upland hay meadows).

This map is one of a series of map prepared as part of 'A Borders Wetland Vision' Project and should only be used in relation to this project.

The soils wetland potential and soils wetland type data derived from the HOST classification are © The Macaulay Institute 2006. These classifications were produced for this project only and should not be used for any other purpose.

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Created by: M.McK date: 13/04/06 Approved by: Date:

Figure A2.10: Purple moor-grass

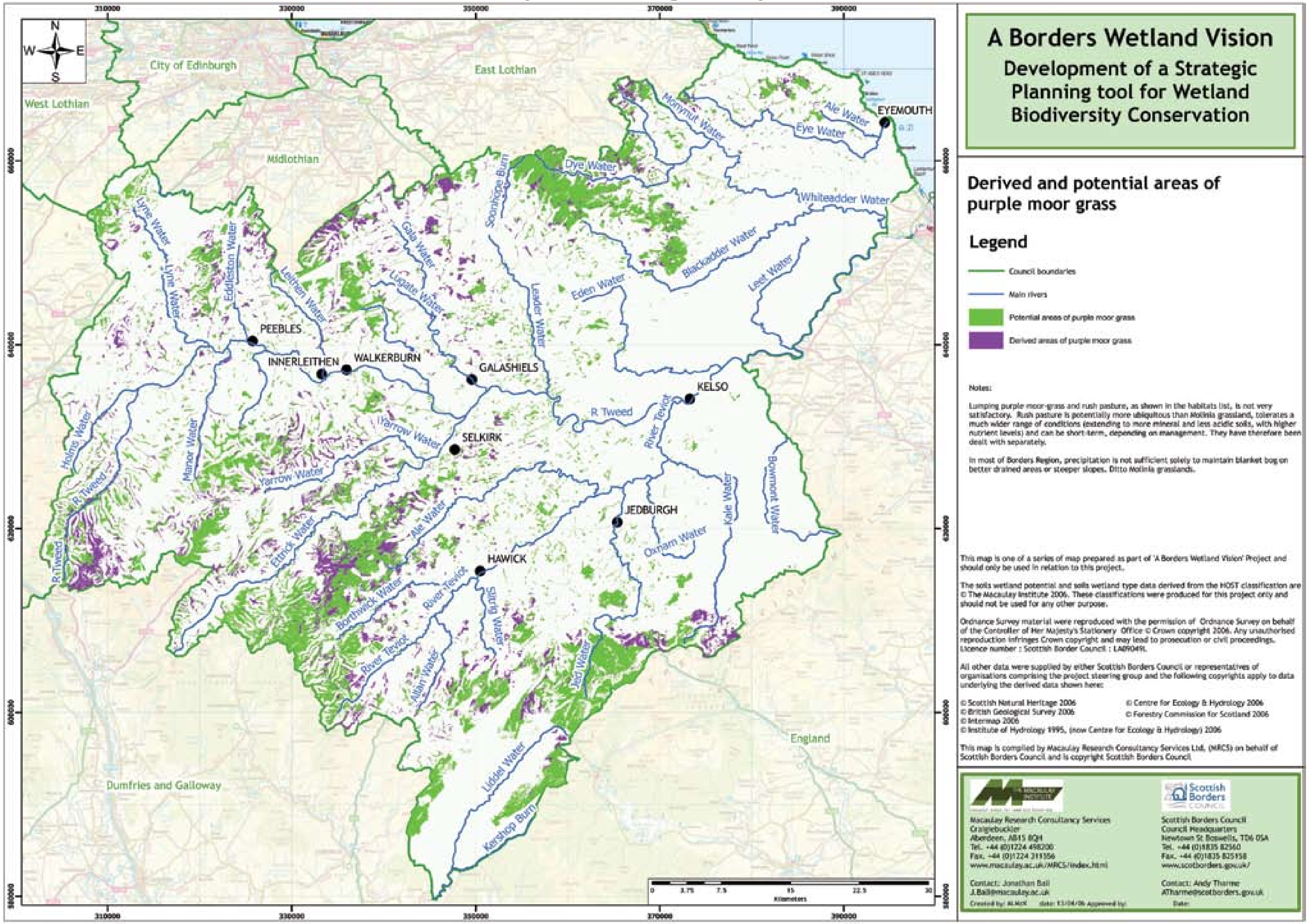


Figure A2.11: Rush pasture

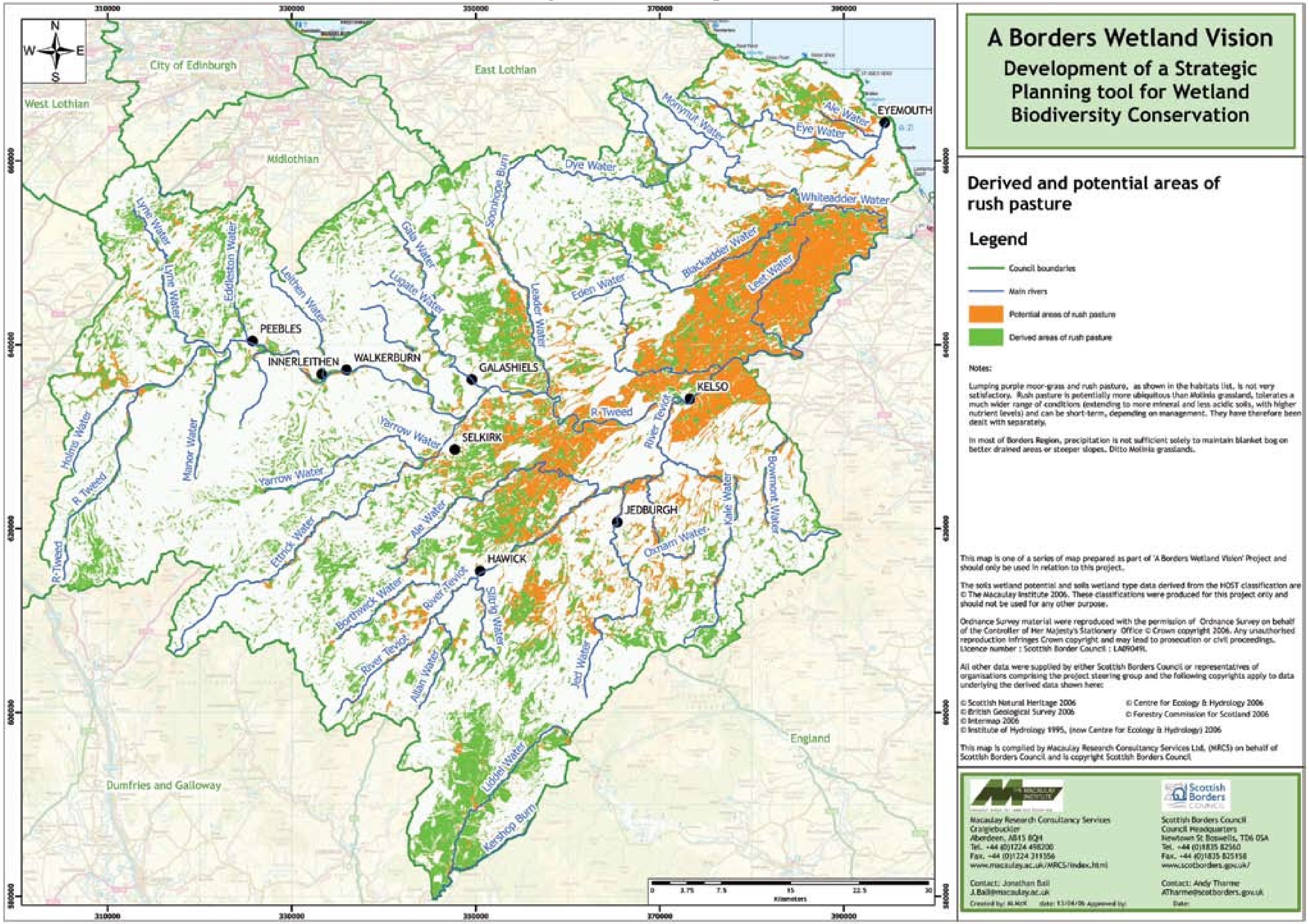


Figure A2.12: Derived and Potential lochs

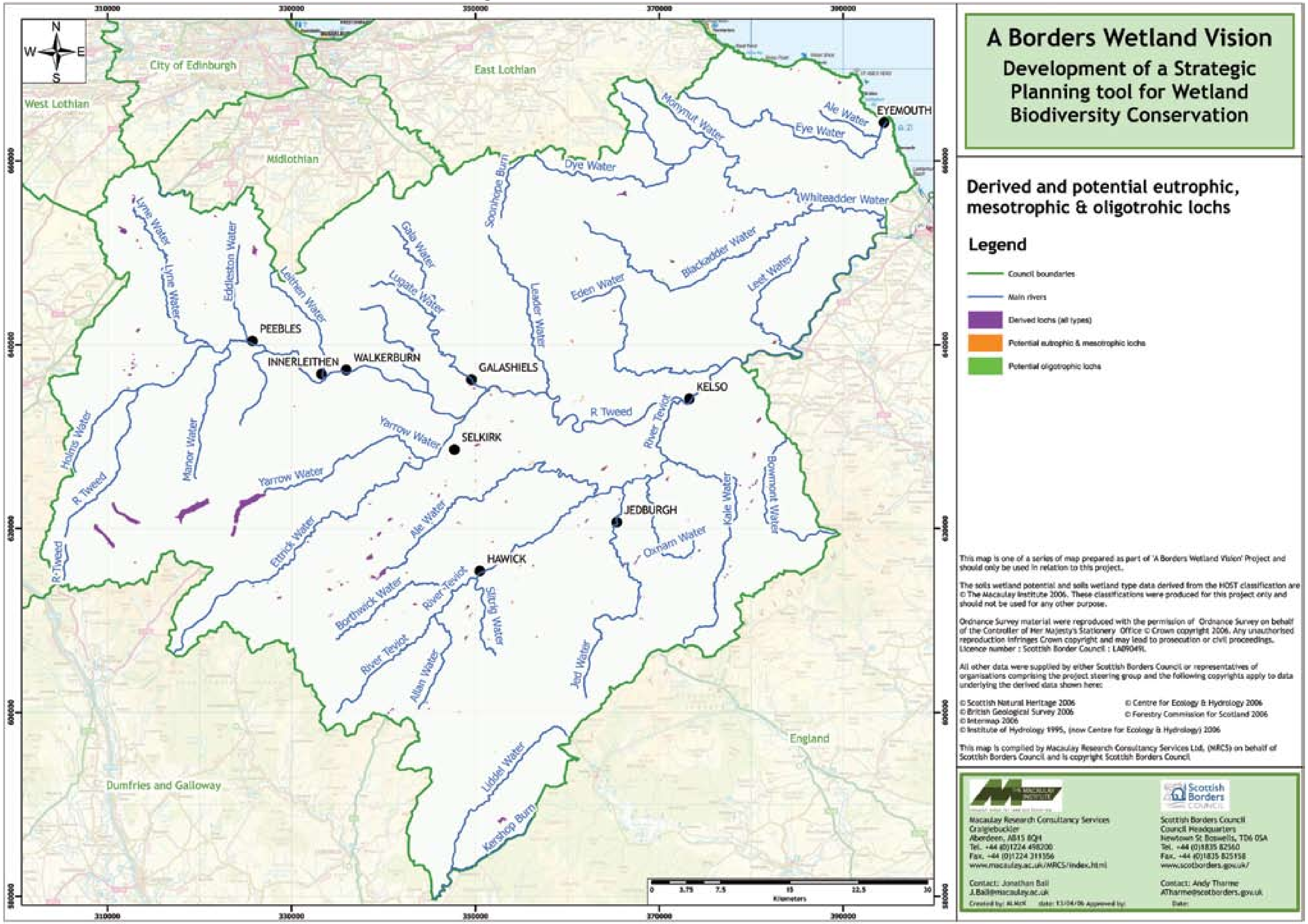
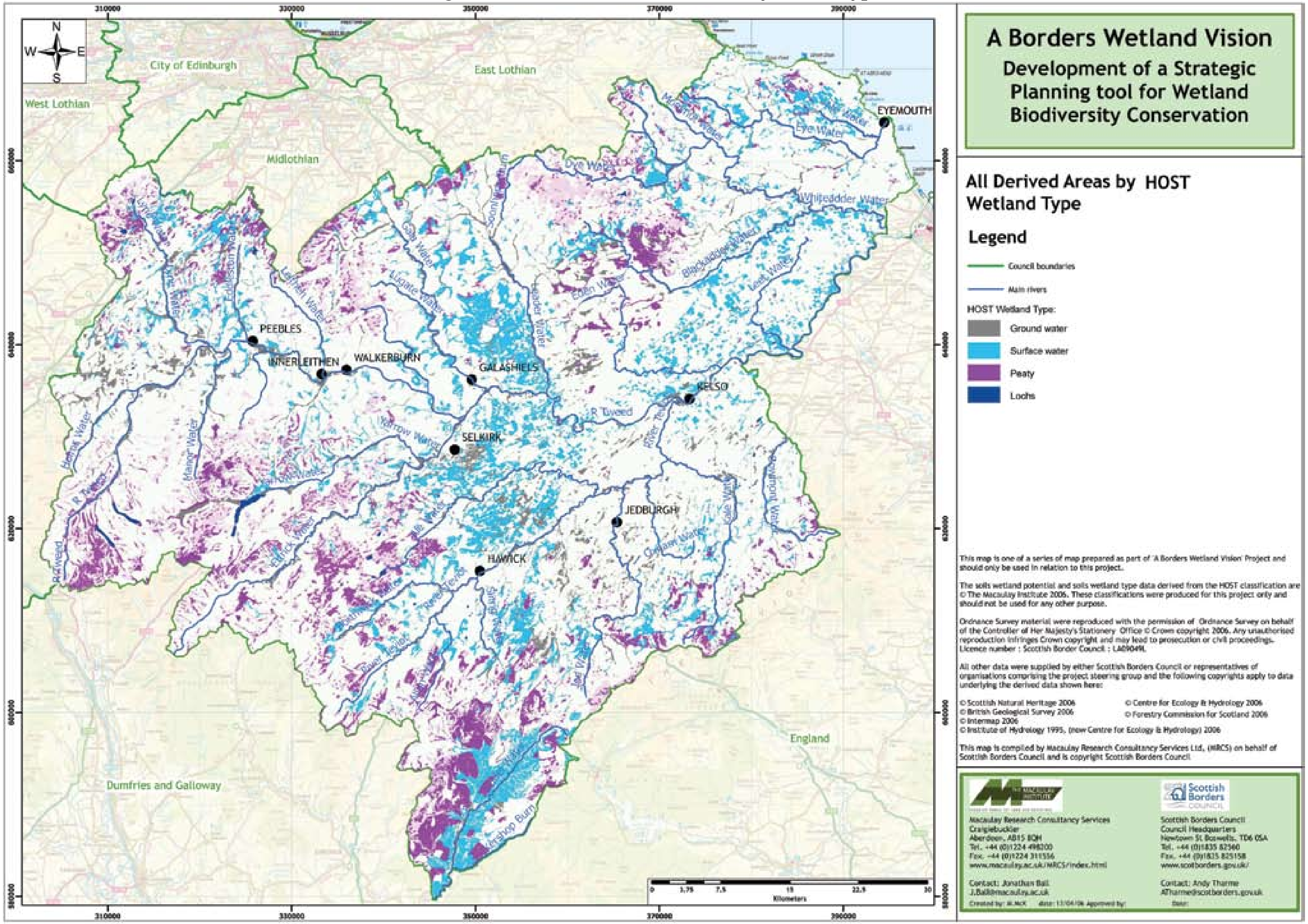


Figure A2.13: All Derived Wetlands by HOST Type



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[3] 'Wetland potential' and 'wetland type' refer here to HOST classification and should not be confused with the modelling outputs of derived wetland *habitat* and potential wetland *habitat*.

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